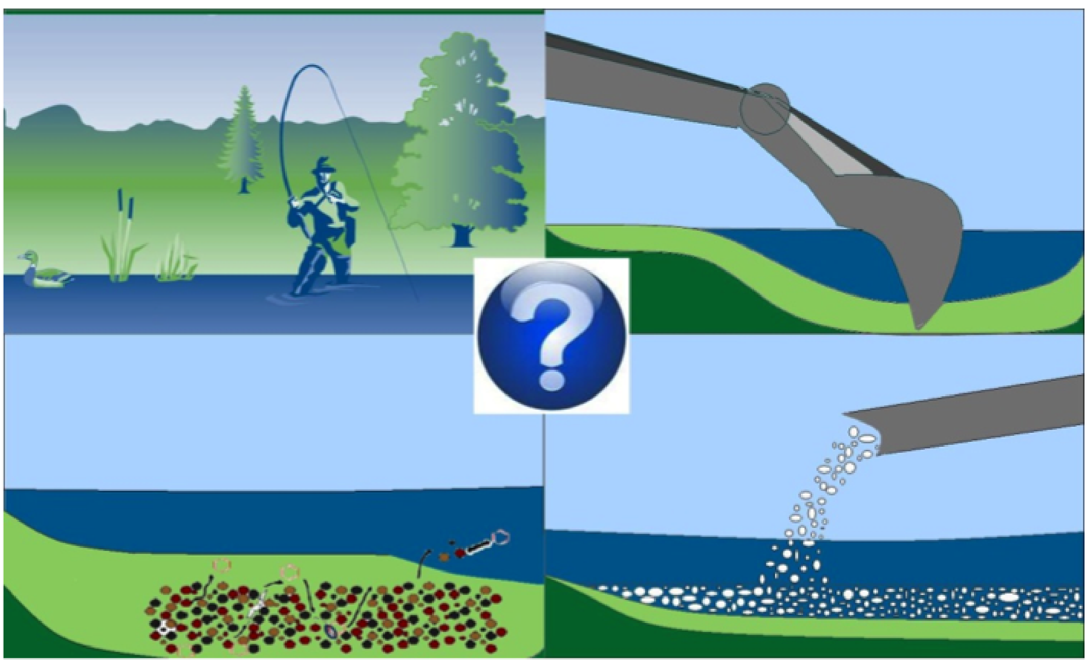
Guidance Document

Contaminated Sediments Remediation

Remedy Selection for Contaminated Sediments



August 2014

Prepared by
The Interstate Technology & Regulatory Council
Contaminated Sediments Team

ABOUT ITRC

The Interstate Technology and Regulatory Council (ITRC) is a public-private coalition working to reduce barriers to the use of innovative environmental technologies and approaches so that compliance costs are reduced and cleanup efficacy is maximized. ITRC produces documents and training that broaden and deepen technical knowledge and expedite quality regulatory decision making while protecting human health and the environment. With private and public sector members from all 50 states and the District of Columbia, ITRC truly provides a national perspective. More information on ITRC is available at www.itrcweb.org. ITRC is a program of the Environmental Research Institute of the States (ERIS), a 501(c)(3) organization incorporated in the District of Columbia and managed by the Environmental Council of the States (ECOS). ECOS is the national, nonprofit, nonpartisan association representing the state and territorial environmental commissioners. Its mission is to serve as a champion for states; to provide a clearinghouse of information for state environmental commissioners; to promote coordination in environmental management; and to articulate state positions on environmental issues to Congress, federal agencies, and the public.

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CS-2

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ITRC (Interstate Technology & Regulatory Council). 2014. *Contaminated Sediments Remediation: Remedy Selection for Contaminated Sediments* (CS-2). Washington, D.C.: Interstate Technology & Regulatory Council, Contaminated Sediments Team. http://www.itrcweb.org/contseds_remedy-selection.

ACKNOWLEDGMENTS

The members of the Interstate Technology & Regulatory Council (ITRC) Contaminated Sediment Remediation Team wish to acknowledge the individuals, organizations, and agencies that contributed to this Web-based Technical and Regulatory Guidance.

As part of the broader ITRC effort, the Contaminated Sediments Remediation Team effort is funded primarily by the U.S. Department of Defense. Additional funding and support have been provided by the U.S. Department of Energy and the U.S. Environmental Protection Agency and the ITRC Industry Affiliates Program (IAP). ITRC operates as a committee of the Environmental Research Institute of the States, a Section 501(c)(3) public charity that supports the Environmental Council of the States through its educational and research activities aimed at improving the environment in the United States and providing a forum for state environmental policy makers.

The Contaminated Sediment Remediation Team wishes to recognize the efforts of Team members who provided valuable written input in the development of this Web-based Technical and Regulatory Guidance. The efforts of all those who took valuable time to review and comment on this document are also greatly appreciated.

The Team recognizes the efforts of the following state environmental personnel who contributed to the development of this Web-based guidance:

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- Jeff Wenzel, Missouri Department of Health and Senior Services
- Araya Vann, Oklahoma Corporation Commission & Envt. Gr for SPE
- Robert Macleod, Michigan Army National Guard

The Team recognizes the contributions of the following community stakeholder and tribal representatives:

- James Heinzman
- Dr. Melinda L. McClanahan, Choctaw Nation of Oklahoma

The Team recognizes the valuable technical contribution of our academic Team members:

- Ronald Neufeld, University of Pittsburgh
- Danny Reible, University of Texas
- Upal Ghosh, University of Maryland Baltimore County

The Team also recognizes the contributions of the following federal agencies:

- David Barclift, Naval Facilities Engineering Command Atlantic Division
- Kim Brown, Naval Facilities Engineering Command
- Arun Gavaskar, NAVFAC Atlantic
- Amy Hawkins, NAVFAC Engineering Service Center
- Wanda Holmes, Chief of Naval Operations Office
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- James Kitchens, USEPA ORD/NERL/ERD
- Gary Newhart, USEPA – ERT
- Robert Kirgan, USAEC
- Paul Schroeder, US Army Engineer Research and Development Center
- Christian McGrath, US Army Engineer R&D Center (ERDC)
- John Croci, National Guard
- Paul Beam, Department of Energy, HQ EM-12
- Renee Silke, Atomic Energy of Canada Limited

Finally, the Team recognizes the contributions of the following consultants and industry representatives:

- Steve Clough, Haley & Aldrich, Inc.
- KariAnne Czajkowski, Ryan Anderson, Lingke Zeng, Langan Engineering & Environmental Services
- Lois Autie, Haley & Aldrich, Inc
- Jamie Bankston, Barr Engineering Company
- Rick Beach, Dan Cooke, Russ Fraze, Curtis Moss, Kenneth Nilsson, Raymond Stoelting AMEC Environment and Infrastructure
- Kristen Bell, James Hutchens, Mark Nielsen, ENVIRON International Corporation
- Anne Fitzpatrick, AECOM

- John Bleiler, Jun Lu, Tony Payne, AECOM
- Eric Blischke, Mathew Schultz, CDM Smith
- Steven Brown, The Dow Chemical Company
- Grant Carey, Porewater Solutions
- Sandip Chattopadhyay, Tetra Tech
- Devamita Chattopadhyay, Allen Dupont, Steven Momeyer, Sara Montieth, Bhawana Sharma, Mark Stron, Jennifer Wilkie, CH2M Hill
- Jeff Clock, EPRI
- John Collins, AquaBlok, LTD
- Paul Doody, Anchor, QEA
- Michael Erickson, Arcadis U.S., Inc
- Richard Evans, Groundwater and Environmental Services, Inc
- Ryan Fimmen, David Himmelheber, Amanda Hughes, Thomas Krug, Derek Tomlinson, Geosyntec
- Michael Firth, ExxonMobil
- Tamara Sorell, Brown & Caldwell, Inc.
- Chuck Geadelmann, William Hague, Honeywell International Corp.
- Stephen Geiger, Kris Hallinger, Auther Taylor, ERM Group, Inc.
- Nancy Grosso, DuPont
- Alan Harris, EMCBC
- Jay Hodney, Jim Whetzel, W. L. Gore & Associates, Inc.
- Kendrick Jaglal, O'Brien & Gere
- Mike Johnson, St. John-Mittelhauser & Associates, Inc.
- Andrew Joslyn, Golder Associates
- Mark Kluger, Dajak, LLC
- Michael Lam, Conestoga Rovers & Associates
- Mike Lawson, Rajesh Singh, Kleinfelder
- Emma Hong Luo, Chevron
- Charles A. Menzie, Exponent
- Daniel Michael, Neptune and Company, Inc.
- Christine Nancarrow, Gregory Tracey, SAIC
- Jim Occhialini, Eileen Snyder, Alpha Analytical
- Martin Offenhauer, Trevet Environmental
- Jim Olsta, CETCO
- Mark Otten, Stephen Warren, Parsons
- Robert Paulson, We Energies
- Abhijeet Prasad, Acuity Environmental Solutions
- John Reddy, Sterling Global Operations, Inc.
- George Shaw, ACI
- Russel Short, EA Engineering, Science and Technology, Inc.
- Eric Stern, Battelle Memorial Institute

The contributions from all of these team members varied through team meetings, many video conference calls, e-mails, and individual telephone calls throughout the duration of the project. The

efforts of all team members, however, resulted in a valuable guidance document that can be used by everyone in the field. A respectful thanks goes to all.

EXECUTIVE SUMMARY

Remediation of contaminated sediments commonly targets the complimentary goals of protecting human health and the environment and restoring impaired environmental resources to beneficial use. Although the selection and implementation of sediment remedies can be straightforward for simple sites, many contaminated sediment sites are challenging from a technical and risk-management perspective. This guidance document offers a remedy selection framework to help project managers evaluate remedial technologies and develop remedial alternatives (often composed of multiple technologies) based on site-specific data. General categories of contaminated sediment remedial technologies covered in this guidance document include monitored natural recovery (MNR) and enhanced monitored natural recovery (EMNR); in situ treatment; capping (conventional and amended); and removal (dredging and excavation). Technology overviews summarize each technology; provide references for more detailed information, describe recent advancements, and offer supporting case studies. The technology overviews also include technology assessment guidelines (TAGs) for guiding the evaluation using site-specific data.

The remedy selection framework includes 6 steps:

1. Review the site characteristics.
2. Identify and map remedial zones.
3. Screen remedial technologies.
4. Evaluate remedial technologies
5. Develop remedial action alternatives.
6. Evaluate remedial action alternatives.

Step 1 consists of a preliminary review of site characteristics relevant to the evaluation of remedial technologies. These site characteristics have been grouped into four categories: physical, chemical, sediment, and land and waterway use. Data regarding these characteristics are typically collected during a remedial investigation and are often used to support the development and refinement of a conceptual site model. Table 2-2 lists the primary characteristics that should be used to evaluate remedial technologies at a site. An initial review of these characteristics can help to determine whether additional data is required to support the remedy selection process.

In Step 2, one or more remedial zones are established for a site. Complex contaminated sediment sites often include one or more remedial zones because of differing characteristics in each zone. Initially, contaminant concentrations and distributions are used to identify zones. These zones may be further refined by evaluating site-specific data relative to the characteristics presented in Table 2-2. Each zone may require the use of more than one remedial technology, in parallel or sequence, to achieve the remedial goals for the zone.

Step 3 consists of preliminary screening to identify the most favorable technologies based on site-specific data. Table 2-3 summarizes conditions that are favorable for a given technology. This table is accompanied by an *interactive Remedial Technology Worksheet* that can be downloaded from the ITRC website and used to screen each zone. Completion of the screening element of the worksheet populates another worksheet for technology evaluation. Only those technologies that are identified as favorable for each zone are carried forward to the evaluation worksheet. The completed worksheet is used in Step 4.

In Step 4, site-specific characteristics are used to further evaluate the remaining remedial technologies following the screening process. Table 2-4, "Summary of Key Site Characteristics," links to the sections in each technology overview that describe how each site characteristic applies to the given technology. Table 2-4 also defines the relative importance of each characteristic for each remedial technology as critical (H), contributing (M), or unimportant (L). Critical characteristics influence the implementability of the remedial technology, and thus determine whether the technology is applicable in a given zone.

The technology overviews include TAGs, which simplify the technology evaluation process. TAGs are quantitative or qualitative guidelines based on simplified models, relationships, and experience that help to evaluate the potential effectiveness and feasibility of remedial technologies. The TAGs can be used as generalized, practical guidelines in a weight-of-evidence approach, but are not pass/fail criteria. If a cell within Table 2-4 contains a TAG symbol, then clicking the link in that cell opens the text that defines the particular TAG and describes its relevance to a particular remedial technology.

Technology Overviews

- *Monitored Natural Recovery and Enhanced Monitored Natural Recovery*
- *In situ Treatment*
- *Conventional and Amended Capping*
- *Removal by Dredging and Excavation*

The information that is accessible through links in Table 2-4 is used to complete the remedial technology evaluation worksheet. Each cell of the worksheet should be completed for at least all critical (H) and contributing (M) characteristics for each applicable technology. The output of this worksheet identifies the technology (or technologies) most favorable within a remedial zone based on site-specific characteristics.

In Step 5, technologies that are determined to be most favorable, based on this multiple lines-of-evidence approach, are used to develop remedial action alternatives. A remedial action alternative may include single or multiple combinations of remedial technologies to achieve remedial action objectives. Developing remedial action alternatives requires consideration of a wide variety of factors that may sometimes be in conflict with one another. The remedy selection framework describes six principles for consideration during development of remedial action alternatives:

1. Focus on achieving remedial action objectives and net risk reduction.
2. Balance short-term effects against long-term risk reduction and permanence.
3. Address high concentration areas that may serve as ongoing sources.
4. Acknowledge uncertainty.

5. Assess cost effectiveness.
6. Consider risk management.

These principles should be considered by agencies, responsible parties, and community stakeholders during the development and evaluation of remedial action alternatives at a contaminated sediment site. Using these principles, remedial action alternatives should be assembled from the favorable technologies identified in each remedial zone into a comprehensive suite of technologies capable of achieving the remedial goals for the contaminated site.

In the final step, Step 6, remedial action alternatives are evaluated for the site. At federal Superfund sites, the National Contingency Plan (NCP) identifies nine evaluation criteria to be used. Since many contaminated sediment sites are not remediated under Superfund, this guidance includes the nine NCP criteria and several additional criteria deemed important for consideration when evaluating remedial action alternatives. These additional criteria include the use of green and sustainable remediation technologies, habitat and resource restoration, watershed considerations, and future land and waterway use.

Even though specific evaluation criteria are provided, their use in remedy selection must be in concert with the requirements of the applicable regulatory framework and the authority providing oversight. This guidance does not change nor supersede existing laws, regulations, policies, or guidance. Specific federal, state, or local regulatory program policies are not specified in this guidance. Therefore, potential regulatory compliance requirements and potential stakeholder preferences must be identified and considered, as appropriate, for a given site when using the remedy selection framework and technology overviews.

Finally, this guidance document identifies three types of monitoring (baseline, construction, and post-remediation) applicable to the successful selection, implementation, and assessment of the various remedial technologies. Monitoring strategies are also presented. Community and tribal stakeholder concerns are also addressed, and multiple case studies describing application of the technologies are provided in Appendix A.

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1.0 INTRODUCTION

Discharges associated with past human activities near lakes, rivers, and estuaries have led to contamination of the sediment underlying these water bodies. Currently, U.S. waterways in every region and every state contain contaminated sediments (see *Handbook for Developing Watershed Plans to Restore and Protect Our Waters*, USEPA 2008a). Contaminated sediments are often located in sensitive, aquatic systems and may affect both human health and the surrounding ecology. Consequently, the remedial decision-making process is often complex, because it must adequately address a number of factors in order for the remedy to be successful.

As the science of sediment remediation has evolved over the last two decades, so has the available guidance. Most of the currently available guidance addresses a specific type of sediment remediation technology, such as monitored natural recovery (MNR), enhanced monitored natural recovery (EMNR), in situ treatment (IST), capping, or removal. The available guidance does not, however, provide a systematic approach to compare and evaluate individual sediment remedial technologies or remedial alternatives for use at a contaminated sediment site.

The purpose of this guidance document is to help site managers select effective contaminated sediment remediation technologies (and an eventual comprehensive remedy) based on site-specific physical, sediment, contaminant, and land and waterway use characteristics. Additionally, this guidance discusses remedy evaluation parameters that include factors such as cost and stakeholder concerns. Although this guidance focuses on evaluating remedial technologies, it may also be used during site characterization to help ensure that the site data necessary to evaluate remedial technologies are collected.

1.1 Document Organization

This ITRC web-based guidance document presents a remedy selection framework for contaminated sediments (selection framework) designed to help identify the most favorable remedial technologies for use at a site (see Chapter 2). Initially, the selection framework evaluates site-specific characteristics and data to define zones of a contaminated site. After an initial screening step to rule out technologies that are clearly not viable, the selection framework offers guidance for a more detailed analysis of site conditions and possible uses for the remaining remedial technologies, and then provides remedy selection parameters for assessing possible remedial alternatives.

1.1.1 Remedy Selection Framework

Chapter 2, Remedy Selection Framework, describes the site specific characteristics needed to evaluate remedial technologies. Four key tables are provided in Chapter 2:

1. Table 2-2. Summary of Site Characterization Needs for Contaminated Sediment Sites
2. Table 2-3. Initial Screening of Remedial Technologies Worksheet

3. Table 2-4. Summary of Key Site Characteristics for Remedial Technologies
4. Table 2-5. Remedial Technology Evaluation Worksheet

These tables summarize useful information or provide links to additional information that should be used to complete the following tasks:

- Identify the necessary site characterization data to establish remedial zones.
- Summarize key site-specific characteristics that help to evaluate remedial technologies within each zone.
- Perform a preliminary screening of remedial technologies within each site zone.
- Evaluate applicable or favorable remedial technologies within each site zone.
- Identify and evaluate preferred alternatives within each site zone or across all site zones.

1.1.2 Technology Overviews

The selection framework is supported by technology overviews that describe how specific site characteristics may influence the applicability of a particular remedial technology. The remedial technologies covered in this document include:

- MNR and EMNR
- in situ treatment
- capping (conventional and amended)
- removal (excavation and dredging)

The technology overviews include the following information about each technology:

- description of the technology
- recent technology advancements and relevance to various site conditions
- references to current technology-specific guidance, research, and case studies
- experience-based technology assessment guidelines (TAGs, noted in text with TAG) that provide quantitative or qualitative guidance to evaluate how site-specific data may influence the selection of a remedial technology

1.1.3 Monitoring

Chapter 7, Monitoring, provides requirements for monitoring during and post remedy implementation. Monitoring is an essential component of all sediment remedies and determines the overall effectiveness of the remedy.

1.1.4 Community and Tribal Stakeholder Input

Involvement with community and tribal stakeholders throughout the decision-making process is an essential step in the selection of an acceptable remedy (Chapter 8). Parties who can contribute important, early input include directly affected residents, businesses, tribal communities, responsible parties, elected officials, local environmental advocacy groups, and others. An effective collaborative process gathers input from affected parties using criteria described in Section 2.9.

1.2 Using This Guidance Document

Most of the data describing site characteristics are collected during the remedial investigation phase of site cleanups and form the basis of a conceptual site model (CSM); see ITRC CS-1 2011, Chapter 2, for a more complete discussion of CSMs. This guidance document applies best at sites where the following information is available to support technology evaluation and remedy selection:

- The nature and extent of contaminants of concern (COCs) and other on-site characteristics have been sufficiently defined to support site understanding, technology evaluation, and remedy selection. If sufficient data are not available to properly evaluate remedial technologies, additional information may be needed in order to effectively use the selection framework.
- Human health and ecological risk assessments have been completed for the site and have determined that the site poses an unacceptable risk.
- Receptors that are to be protected or endpoints that are to be achieved have been identified.
- Contaminant loading by releases from site-related source areas has been controlled or their ongoing contribution to site sediment contamination has been determined (Section 2.2).
- Remedial action objectives (RAOs) have been established. For additional details on RAO development, see Section 2.4 of *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (USEPA 2005a).

This guidance can be applied to contaminated sediment sites in freshwater or marine environments, including creeks, rivers, streams, wetlands, ponds, drainage ditches, impoundments, lakes, reservoirs, harbors, estuaries, bays, intertidal zones, and coastal ocean areas.

The primary audience for this guidance includes state and federal project managers, as well as practitioners, consultants, and responsible parties faced with evaluating remedies at contaminated sediment sites. Community and tribal stakeholders may also find this document useful. Using this guidance requires a working knowledge of contaminated sediment characterization, exposure assessment, and sediment remediation. Finally, this guidance does not impose or create additional legal requirements for contaminated sediment remediation.

1.2.1 Using this Guidance Document for Remedial Investigations

Although this guidance focuses on the evaluation of remedial technologies for contaminated sediment sites in the remediation phase, the selection framework may also be used during the remedial investigation (RI) phase to help identify the site data necessary to evaluate remedial technologies. As the RI of the site progresses and the CSM is refined, Table 2-2 (Summary of Site Characterization Needs for Contaminated Sediment Sites) and Table 2-4 (Summary of Key Site Characteristics for Remedial Technologies) can be consulted to help determine site-specific data needs. This data evaluation may benefit sites that are candidates for early action cleanups.

1.2.2 Determining Data Adequacy

As a site CSM is refined, professional judgment must be used to determine the additional data needed for remedy selection. The selection framework initially relies on the evaluation of site-specific characteristics and related data to help identify the most favorable remedial technologies. Although this guidance helps to focus site characterization activities and data gathering, the level of data available to support the remedy selection process varies based on the degree of complexity at a site. Generally, having more key data available to support the technology evaluation process results in a higher degree of confidence that the selected remedy will achieve RAOs. However, each site has a point of diminishing returns, where the collection of additional data will no longer markedly improve the remedy selection process. At this point, site managers must determine whether additional data are needed to support the final selection of a remedy. USEPA provides guidance on this topic as part the development of Data Quality Objectives in *Guidance on Systematic Planning Using the Data Quality Objectives Process*, (USEPA 2006e).

1.2.3 Using Technology Assessment Guidelines

This guidance presents qualitative and quantitative technology assessment guidelines (TAGs) which help to determine whether site conditions are generally amenable to a particular sediment remedial technology. TAGs are not meant to be prescriptive but rather provide a range of reasonable parameters and perspectives in remedy selection. Therefore, more detailed evaluation of site specific data and parameters may be necessary if site conditions are slightly outside the bounds of a given technology assessment guideline. Site characteristics that have TAGs are identified in Table 2-4 with a symbol (). TAGs are also *italicized* in context within the technology overviews.

1.3 Determining Regulatory Compliance

Specific federal, state, or local regulatory program policies are not specified in this document, therefore, potential regulatory compliance issues and potential stakeholder issues must be identified for a site prior to using the selection framework and supporting technology overviews.

Most, if not all, contaminated sediment remedies will fall under the jurisdiction of a state or federal regulatory agency, and many of the activities associated with sediment remedial actions (such as dredging, capping, or dewatering) require permits. Early in the remedial process, site managers must consult with the agencies providing oversight in order to comply with applicable regulations and to obtain needed permits. In some cases, the implementation of a remedy, such as the use of in situ treatment (Chapter 4) or amended (such as reactive) caps (Chapter 5) may require additional permitting or regulatory approval.

Agencies such as the United States Fish and Wildlife Service, National Oceanic Atmospheric Administrations, and National Marine Fisheries Service may regulate certain aspects of a sediment remedial action and require that relevant permits be obtained. Tribal lands ceded as Usual and Accustomed Areas are co-managed by federal and tribal jurisdiction and may influence the sediment remedial selection process (see Chapter 8). Because the need for permits depends on site-specific conditions (such as habitat types, presence of navigational waters, or threatened or endangered species) the information presented here should not be considered all inclusive; rather, it is intended to make the reader aware that sediment remedial actions may require coordination with multiple agencies. These agencies may directly affect both the implementation (remedial activity timing restrictions) and the selection of a remedy. Ultimately, it is the practitioner’s responsibility to address the requirements of all applicable local, state, tribal, and federal regulations.

2.0 REMEDY EVALUATION FRAMEWORK

Technical complexity at contaminated sediments sites arises from the physical, chemical, and biological characteristics of the site, spatial variability, and changes that the system undergoes during and after remedial activities (for example, a change in contaminant bioavailability or characteristics of the sediment bed). Because of the inherent complexity of these projects, site characteristics (such as source areas, transport mechanisms, background and upstream areas, and key site features) should be clearly identified in a CSM before evaluating and selecting remedial alternatives. This chapter provides guidance for selecting appropriate remedial technologies based on these site-specific conditions.

The stepwise selection approach presented here includes a series of tables and worksheets that help identify applicable remedial technologies to achieve RAOs for a site or zone within a site. Overviews of these remedial technologies are provided in subsequent chapters. While the list of potential site characterization needs for remedy selection is extensive, the data for all of the characteristics listed in Table 2-2 and Table 2-4 may not be required for remedy selection at every site. Specific data requirements are a function of the water body being evaluated, the CSM, and site-specific conditions.

Although sediment remediation is often completed under federal or state cleanup programs, these projects should also be considered within the context of broader goals to revitalize and restore the watershed. From the beginning, site managers should coordinate and communicate with stakeholders to achieve broader watershed goals (see ASTSWMO 2009). Stakeholder concerns (including those of tribal stakeholders) are addressed in Chapter 8.

About the Remedy Evaluation Framework

The remedy evaluation framework presented here assists in selecting remedial technologies and evaluating remedial alternatives that are applicable to contaminated sediment sites based on site-specific conditions. The effectiveness, feasibility, and cost of the remedies presented here depend on site specific physical, chemical, and biological characteristics and other risk-related factors. Consult the site characteristics described in Table 2-2, Table 2-3, and Table 2-4 (and in more detail in the subsequent technology overview sections) during the remedial investigation (RI) stage of a project to identify factors that affect the evaluation of technologies and selection of a remedy.

The framework includes worksheets for preliminary screening and then detailed evaluation of up to seven technologies: monitored natural recovery (MNR), enhanced MNR (EMNR), in situ treatment (IST), conventional capping, amended capping, and removal through dredging or excavation. After favorable remedial technologies are screened in based on site-specific characteristics, the framework describes key parameters used to develop and evaluate remedial alternatives.

In selecting remedial alternatives, consider factors beyond site-specific characteristics such as the ability of a specific remedial technology to achieve RAOs, long term effectiveness, technical feasibility, regulatory acceptance, stakeholder concerns, sustainability, and costs (see Section 2.9).

Often, one or more of these factors are given more weight than others in the final selection of a remedial alternative. Recent innovations in multi-criteria decision analysis (MCDA) provide systematic approaching assigning weights to various evaluation factors. Section 2.9 describes various approaches and criteria that can be used in this evaluation, but ranking their importance is left to the parties involved in remedy selection. Experienced, professional judgment must be applied in evaluating site-specific criteria to identify the best remedial technologies for a particular site.

Remedy Evaluation Framework Steps and Decision Matrix Flow Chart

Steps in the remedy evaluation framework are shown in Figure 2-1 and include the following:

- Step 1. Review Site Characteristics – Review site-specific data to confirm that sufficient information is available to effectively evaluate remedial technologies. Site specific characteristics are grouped into physical, sediment, contaminant, and land and waterway use categories.
- Step 2. Identify and Map Remedial Zones – Delineate the site into one or more remedial zones to identify applicable technologies. Zones can be based on risk, contaminant concentration and extent, contaminant type, physical characteristics and other distinct site characteristics or combinations of characteristics. This step can also identify potential early action candidate areas.
- Step 3. Screen Remedial Technologies – Evaluate technologies based on general criteria first, and screen out obviously inapplicable technologies prior to the detailed evaluation.
- Step 4. Evaluate Remedial Technologies – Use a lines-of-evidence approach to evaluate relevant site characteristics for each remedial zone and to determine which technologies are most favorable within each remedial zone. Lines of evidence and TAGs may also be used to screen remedial technologies at this stage of the evaluation. A TAG is a rough and practical guideline based on experience rather than a scientific or precise guide based on theory. This approach helps to evaluate applicable technologies based on site-specific physical, contaminant, sediment, and land and waterway use data and characteristics.
- Step 5. Develop Remedial Action Alternatives – Develop remedial alternatives by assembling combinations of technologies into alternatives that address contamination on a site-wide basis. This guidance provides a general set of principles to assist with the development of remedial alternatives. Alternatives should be developed for all remedial zones and may consist of technologies applied in combination (such as dredge and cap).
- Step 6. Evaluate Remedial Action Alternatives – Evaluate remedial alternatives, considering factors such as the ability to meet RAOs, long-term effectiveness, short-term impacts, technical feasibility, administrative feasibility, practicality, cost and schedule, green and sustainable remediation, habitat and resource restoration, watershed considerations, and future land and waterway use.

The steps presented here generally follow the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) feasibility study (FS) or Resource Conservation and Recovery Act (RCRA) corrective measures study (CMS) process. The remedy evaluation framework does not replace these processes but rather develops a structured approach for evaluating remedial options at contaminated sediment sites. For example, CERCLA RI/FS guidance from USEPA describes a remedial technology screening step. This ITRC guidance document provides specific information for screening remedial technologies applicable to contaminated sediment sites based on site specific information. Similarly, the NCP describes the remedial action alternative evaluation criteria to be used under CERCLA. This ITRC guidance provides guiding principles for the development and evaluation of remedial action alternatives specific to contaminated sediment sites. Finally, the technology screening steps and guiding principles in this guidance document are applicable to both federal and state environmental cleanup programs.

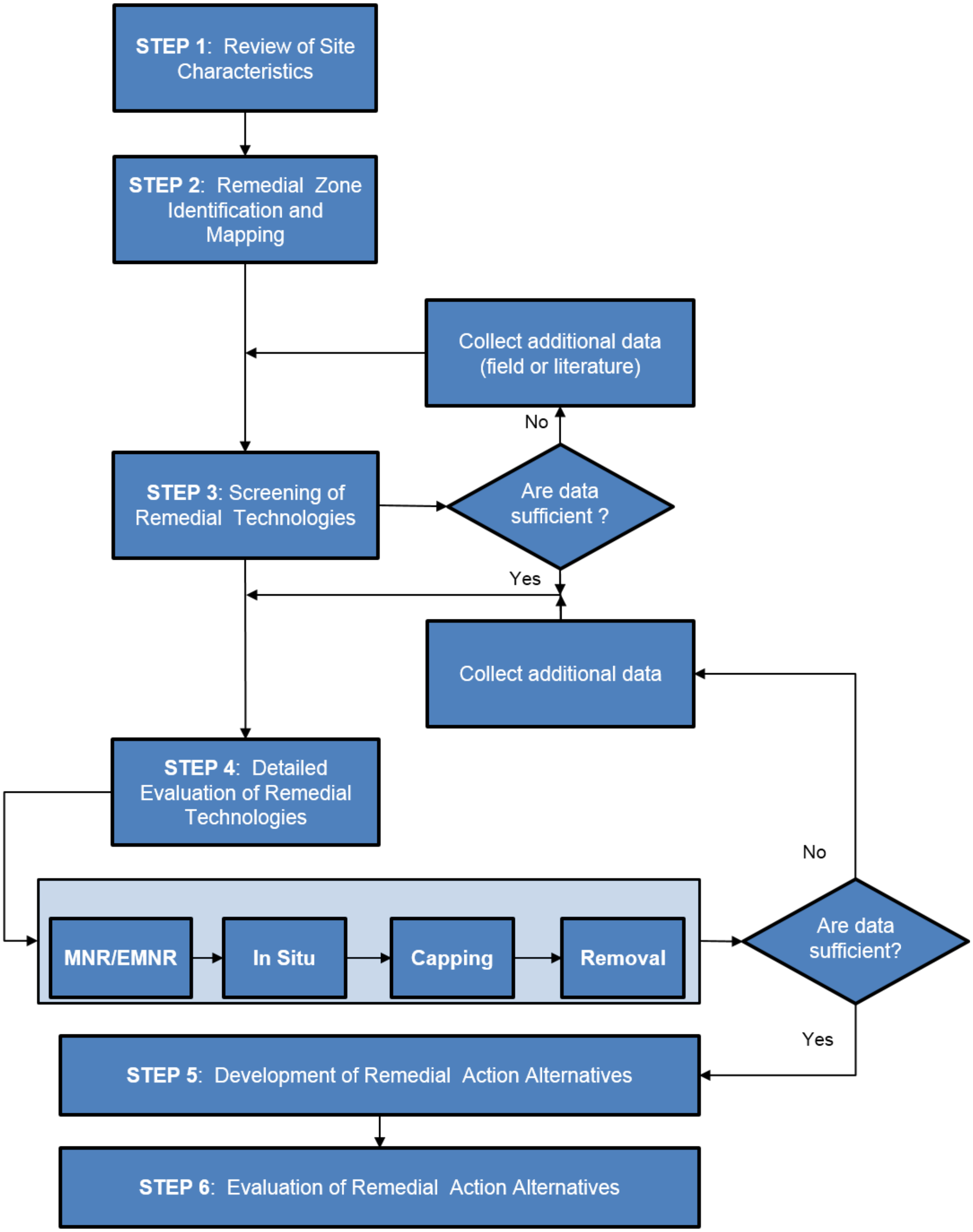


Figure 2-1. Decision matrix flow chart.

Use this framework early in the investigation process to plan the collection of data necessary to evaluate remedial technologies and develop an appropriate remedy.

2.1 Relationship of the Framework to the Technology Overviews

Evaluating remedial technologies requires site-specific information, usually collected during the site characterization phase (remedial investigation). Although the site characterization phase often focuses on establishing the nature and extent of contamination and assessing site risks, the site characterization data needs presented in Table 2-2 should be reviewed to ensure that the data necessary for remedy selection is collected as well. In order to avoid collecting unnecessary data, an iterative approach should be used in order to reduce the uncertainty in the CSM to an acceptable level. To help evaluate site-specific data requirements, two reference tables (Table 2-2 and Table 2-4) are provided. Table 2-4 is linked to the technology overviews. In addition, two worksheet tables are provided (Table 2-3 and Table 2-5). These tables can be used in assimilating and documenting how the reference information applies to site characteristics on a zone-by-zone basis.

- Table 2-2, Summary of site characterization needs for contaminated sediment site and provides details of site characterization needs by type (physical, sediment, contaminant, land and waterway use) for contaminated sediment sites and a summary of the implications of each characteristic on remedy selection.
- Table 2-3, Initial screening of remedial technologies worksheet and presents a worksheet that can be used to screen remedial technologies and identify those that are potentially applicable for each zone.
- Table 2-4, Summary of key site characteristics for remedial technologies and links to TAGs, identifies which data are most important for the evaluation of specific remedial technologies and includes links to applicable sections of each technology overview.
- Table 2-5, Remedial technology evaluation worksheet and presents a worksheet for the detailed evaluation of applicable remedial technologies for each remedial zone.

The technology overviews (MNR/EMNR, in situ treatment, capping, and removal) provide technology-specific details and insight for use in screening and evaluating remedial technologies. To the extent possible, TAGs are used to evaluate site data and are provided in these technical overviews as they pertain to each technology.

2.2 Role of Background Conditions

The term "background" typically refers to substances, conditions, or locations that are not influenced by the releases from a site, and are usually described as either naturally occurring (consistently present in the environment but not influenced by human activity) or anthropogenic (influenced by human activity but not related to specific activities at the site). For example, a number of inorganic metals occur naturally in the soils of specific regions or states due to geologic processes and the mineralogy of the parent bedrock material. Some organic chemicals, such as polychlorinated biphenyls (PCBs), are anthropogenic substances, but have detectable concentrations because they are ubiquitous in the environment and often have long-range, atmospheric transport contributions not related to localized activities. Other organic compounds, such as polynuclear aromatic hydrocarbons (PAHs), have both naturally occurring and anthropogenic sources and are often associated with increasing urbanization, which causes increases in car emissions and street dirt. Many states use the terms natural background, urban background, area background, or regional background to distinguish between different spatial or land use conditions affecting chemical concentrations in a particular region or area. State and USEPA regions may have different definitions and requirements for assessing background conditions as part of environmental site assessments.

Background or reference conditions must be considered in virtually all stages of sediment investigations, remedial technology evaluations, and remedial response actions. This section focuses on background sediment chemistry that is most relevant for selecting and screening remedial technologies but does not address reference areas in terms of toxicity testing for risk assessments.

During remedy selection, background can be used to help develop site-wide remedial goals and prioritize source control efforts. While it is not technically feasible to remediate to below background levels, knowledge of background conditions can help determine goals for a project and estimate when the goals will be met. If the site is larger, source control and remediation efforts may be complimentary, concurrent activities, and knowledge of background conditions may help prioritize and sequence the remedial actions.

The ITRC document *Incorporating Bioavailability Considerations into the Evaluation of Contaminated Sediment Sites (CS-1)* (ITRC 2011a) provides guidance on the role and purpose of background data when evaluating site conditions, risks, and chemicals of potential concern. Typical questions that may be asked when evaluating background data sets at sediment sites include:

- Do the sample concentrations vary with depth?
- Does the particle size distribution or the organic carbon profile indicate that relatively high concentrations tend to occur only in certain types of sediments?
- Does the estimate of the upper bound range depend on nondetect values?
- Does the sample distribution indicate spatial groupings within the site? Are site data consistent with background? Are there temporal variations or indications that the background distribution may be changing?
- What are the concentrations associated with ongoing lateral and upstream sources to the site that can be expected after sediment remediation is complete?

2.2.1 Determination of Background

Background conditions and concentrations for sediment sites are typically determined from reference samples (obtained from upstream or areas unaffected by site-related sources) and may include the following:

- *Sediment samples* are typically surface grab samples but could also be selected from deeper sediment core intervals that represent pre-industrial horizons.
- *Surface water samples* are collected from lateral or upstream stations entering the site. The samples can be discrete samples (grab) or composite samples (collected over time or

integrated over the height of the water column). Contaminant concentrations of suspended solids within a surface water sample maybe used to develop estimates of levels of deposited sediment.

- *Total suspended solids (particulates) samples* are typically collected from stormwater or combined sewer overflow (CSO) outfalls, sediment traps, catch basins, or atmospheric collection traps at locations where water is entering the site or watershed. These samples indicate ongoing background contributions to the sediment bed. Concentrations of suspended solids within a surface water sample may be used to develop estimates of levels in deposited sediment.
- *Residue samples* are typically collected from biota (fish, invertebrates).
- *Community level assessments* typically include benthic invertebrate metrics.
- *Ranges of background concentrations* published by agencies or information in the literature may also be reviewed.

Background data are variable, and samples typically reflect a range of concentrations due to temporal and spatial heterogeneity. Therefore, consider several factors when determining background concentrations from field-collected data (NAVFAC 2003a; WDOE 1992):

- Statistical Considerations of Data
    - distribution of the data (such as lognormal)
    - statistical methods for analyzing background data (probability plots, multiple inflection points, percentiles, geochemical associations, comparative statistics)
    - statistical methods for comparing background data to site data, including sample sizes and statistical detection and uncertainty effects; minimum of 5 to 15 samples typically needed depending on data variability (for example, number of nondetects, and minimum confidence levels), measurement endpoints (such as 90th percentile), and confidence levels (such as 95% confidence on the 90th percentile concentration)
- Sampling Locations and Spatial Considerations
    - data location, such as other water bodies with similar physical conditions or upstream and lateral inputs entering the site
    - temporal trends evident in sediment cores or distribution of data within the site
- Physico-chemical Factors
    - physical and chemical factors (such as total organic carbon, particle surface area, and particle size distribution), which correlate with chemical concentrations in sediments and must be considered when defining background concentrations (ITRC 2011a)

Two USEPA documents, *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites* (USEPA 2002a) and *Role of Background in the CERCLA Cleanup Program* (USEPA 2002b), also provide guidance on determining background concentrations and comparing background to site concentrations. Depending on the data quality objectives (DQOs) and risk-based cleanup levels, concentrations may be compared as point values (either statistical or threshold), as population comparisons (significant differences from reference areas), or spatially-weighted average concentrations. Several state and federal agencies periodically collect regional background data for soils and sediments to determine background concentrations and monitor changes in sediment quality as part of ambient monitoring programs. While not a complete list, these agencies include Washington State Department of Ecology, Michigan Department of Natural Resources, San Francisco Regional Water Quality Board, Oregon Department of Environmental Quality, and the National Oceanic and Atmospheric Administration (NOAA) Status and Trends Program. Washington State, in particular, has started developing area background concentrations for several marine water bodies in Puget Sound (WDOE 2013). These results will be incorporated into the revised State Sediment Management Standards.

2.2.2 Using Background Data

A background data set or threshold value, once calculated, can be used in many stages of a site cleanup including:

- determining if a release has occurred
- determining site boundaries and evaluating site conditions (nature and extent of contamination)
- distinguishing chemicals of potential concern from background chemicals to help refine the list of chemicals of concern
- establishing a cleanup standard from background data
- using reference areas that are physically, geochemically, and ecologically similar to the site to help evaluate the significance of observed effects and risks from chemical exposure
- establishing RAOs
- establishing performance criteria to evaluate compliance monitoring data
- evaluating recontamination potential after remedy implementation (applicable to all remedial technologies)
- assisting with risk communication to the public and stakeholders

For baseline risk assessments, chemicals of potential concern detected at concentrations below background are discussed in the risk characterization, but cleanup levels are not set below the upper bound of the background range (NAVFAC 2003a; USEPA 2005a). Many states consider background concentrations when formulating cleanup levels and recognize that setting numerical cleanup goals at levels below background is not feasible because of the potential for recontamination to the background concentration. Contaminants with elevated background concentrations should be discussed in the risk characterization summary so that the public is aware of their existence, especially if naturally-occurring substances are present above risk levels and may pose a potential environmental or health risk (USEPA 2005a). If data are available, the contribution of background to site concentrations should be distinguished. In these cases, area-wide contamination may be addressed by other programs or regulatory authorities able to address larger spatial areas and source control needs.

When developing cleanup strategies, background concentrations can be used to develop achievable cleanup levels that consider anthropogenic sources, recontamination potential, and pre-remedial contaminant concentrations. In most cases, background conditions are relevant to all remedial technologies. Recontamination potential from ongoing, nonpoint sources is a concern to all sediment cleanup sites regardless of the action taken. For example, sediment caps and sand layers placed as a remedial technology or to manage dredging generated residuals can become recontaminated due to background conditions and areas that have been previously dredged could rebound to site equilibrium concentrations. Background concentrations can also be used to define long-term remedial targets that reflect future source control efforts and the recovery potential of the system. Long-term remedial targets support the overall goal of protecting human health and the environment, even when these targets are below existing background levels, especially for regions with sovereign tribal treaty rights.

Project Example: Lockheed Martin, Seattle WA

The Lockheed Martin Yard 2 marine sediment cleanup site in Seattle, Washington developed several different natural and area background concentrations that reflect different spatial areas, site conditions, and chemical inputs. Sediment samples were collected from reference areas, deep basin, middle bay, and inner bay areas (Table 2-1). A chemical gradient is observed with increasing concentrations from natural background areas toward the more urban shoreline (middle bay) where more outfalls, vessel traffic, and nonpoint source urban contributions are expected. In this project example, some of the middle bay urban background concentrations were used to develop remedial action levels for the site (for dredging and capping), and some of the natural background concentrations were used to develop long-term remediation goals (USEPA 2013b).

Table 2-1. Background concentrations at the Lockheed Yard 2 sediment site (USEPA 2013b)

Parameter	Units	Puget Sound Natural Background (OSV Bold Study, USEPA 2009)[c]	Elliott Bay Sediment Background – Urban Waters Initiative (Ecology 2007)[a]	
			Deep Basin/ Outer Bay	Middle Bay/ Urban[b]
Arsenic	mg/kg dw	7	9.1	8.4
Copper	mg/kg dw	25	41	49
Lead	mg/kg dw	11	27	47
Mercury	mg/kg dw	0.10	0.18	0.44
cPAHs	mg/kg dw	9	125	757
Total PCBs	mg/kg dw	2	48	119
Dioxins/furans	ng TEQ/kg dw	2	NA	NA

Notes:
NA = not analyzed
a. These background data are affected by both point and nonpoint pollutant sources in Elliott Bay and are not representative of natural background. Calculated based on the 95th percentile of the upper confidence level (95 UCL). Two samples were taken from the outer bay, 13 samples from mid-bay, and 15 samples from inner bay.
b. Some of the urban background concentrations were used to establish remedial action levels for sediment cleanup.
c. Data is from the *OSV Bold* survey vessel study. Some of the natural background concentrations were used to establish long-term remediation goals for the project. Calculated based on the 95th percentile of the upper confidence level (95 UCL). 70 samples were taken.

Project Example: East River Site, New York NY

In a second project example from the East River Site in New York City, background levels were computed to achieve a range of PAH concentrations collected from depositional sediment areas located north and south of the site (upstream and downstream, n = 40 samples, 3 outliers removed). Background concentrations ranged from 60 to 116 mg/kg dry weight (dw) using several different statistical metrics (98th percentile of empirical data distribution function, upper prediction limit, 90th percentile of ranked data, and 95% UCL). An almost two-fold difference exists in the results from the different methods. The 90th percentile value (71 mg/kg dw) for total PAHs was selected as the background threshold value for the site (AECOM 2013).

2.2.3 Source Control and Background Conditions

Increased concern over the intersection of industrial pollution in the United States with population growth and urbanization has led to a greater need to understand the background concentrations of certain chemicals in the environment, and to determine reasonable and achievable, yet protective, cleanup levels. Controlling sources of contamination to a sediment site to the maximum extent practical, from both on-site and off-site sources, is an explicit expectation of a sediment cleanup, especially when monitored natural recovery is part of the remedial action or recontamination is of concern. The purpose of source control is to prevent ongoing releases of contaminants to the sediment bed at concentrations that would exceed the sediment cleanup levels. Understanding background concentrations can help to quantify ongoing inputs to the site from ambient sources. In general, background levels represent contaminant concentrations that are not expected to be controlled. These concentrations are the lower limit expected from source control efforts for a sediment site cleanup.

Source control may be managed as early actions and hotspot removals, managed as different operable units or cleanup sites, or managed through a separate regulatory program. A comprehensive source control strategy may call upon different regulatory programs and agencies to implement an area-wide strategy. These agencies can use their regulatory authority to promote source control in a variety of ways: source trace sampling, stormwater and CSO programs, hazardous waste and pollution prevention programs, catch basin and shoreline inspection and maintenance programs, permits, education and best management practices, water quality compliance and spill response programs, and environmental assessments. In some instances, long-term monitoring can be used to determine what the technically practical lower limits are for site concentrations, and where source control efforts should be focused.

Source control actions can take various forms, or may not be required at all in some instances. For example, enforcement of source control actions at the Thea Foss cleanup site in Washington State is addressed through an education campaign including encouraging marinas to get “EnviroStars” certification and preparing an "Only Rain in the Drain" campaign. For the Fox River cleanup site in Wisconsin, the remedy plan notes that point sources of contaminants are adequately addressed by water discharge permits for the Fox River and that no additional source control actions are necessary. For the Hudson River site in New York, a separate source control action near the General Electric (GE) Hudson Falls plant is being implemented by GE (under an administrative order issued by NYSDEC) in order to address the continuing discharge of PCBs from that facility.

2.2.4 Water Quality Standards and Background Conditions

Under CERCLA, state water quality standards are typically considered to be applicable or relevant and appropriate requirements (ARARs). Because ARARs are threshold requirements, water quality standards must be met or a waiver must be obtained (USEPA 1999a). At many sites, water quality standards for chemicals such as dioxins/furans and PCBs are not achievable due to background conditions. For example, at the Lockheed Martin Yard 2 site in Washington (USEPA 2013b), a technical impracticability (TI) waiver was used to waive the requirement to meet water quality standards because of technological limitations associated with the background condition. At sites where background concentrations exceed water quality criteria, consultation with federal and state cleanup and water quality authorities will be required to develop the appropriate approach for demonstrating that the proposed cleanup action complies with water quality requirements (for example, TI waiver, change water body use designation, or use other types of ARAR waivers).

2.3 Source Control

The framework for evaluation of remedial technologies presented herein assumes that source control has either been achieved or that sources are well understood and integrated with the sediment remedy to prevent recontamination. Identifying and controlling the sources of contaminants to an aquatic system is an integral component to remediating contaminated sediments and effective source control is a prerequisite for applying any of the remedial technologies described in this guidance (USEPA 2005a, Section 2.6):

> In most cases, before any sediment action is taken, project managers should consider the potential for recontamination and factor that potential into the remedy selection process.

The Association of State and Territorial Solid Waste Management Officials (ASTSWMO) evaluated recontamination of sediment sites that had been remediated, including numerous case studies, and concluded that recontamination has been observed at a number of sites where contaminated sediments had been remediated, highlighting the importance of adequate source control (ASTSWMO 2013). As a result, characterization should include ongoing sources that may adversely affect the aquatic system and potentially prevent attainment of remedial objectives. Sediment remediation is unlikely to be effective unless sources that could result in unacceptable sediment recontamination have been identified and controlled to the extent practical.

Sources that should be controlled can include the following:

- ***In-water sources.*** These sources are characterized by elevated sediment contaminant concentrations associated with current or historical releases to the water body that represent an ongoing source of contamination to downstream or adjacent areas of the water body. In-water sediment sources may result in recontamination if not addressed through sediment remedies. As part of an adaptive management approach to remediating sediment contamination in a water body, in-water sources should be considered for early action remediation.

- ***Land-based sources.*** Land based sources of contamination include contaminated soil that may migrate to water bodies by erosion and overland sheet flow, stormwater discharge, terrestrial activity (for example, wind-blown materials, soil or sediment creep, or improper use of engineering controls), erosion of contaminated bank soils, or episodic erosion of floodplain soils during high flow rates. In some situations, contaminated groundwater discharges may also transport contaminants to sediment and surface water. When these sources are adjacent to an area of sediment contamination and may be included within the site boundary, they should be adequately controlled prior to, or in conjunction, with the in-water sediment cleanup.

- ***Watershed sources.*** Sediment contamination may result from regional watershed activities. Nonpoint sources resulting from atmospheric deposition, urban and agricultural activities may contribute to ambient sediment contamination at a regional or watershed level. While these sources may be difficult to control, they must be considered when setting remedial goals. Background contamination is a related, but separate, matter and is discussed in greater detail in Section 2.2.

Sources can be current or historical; source control efforts should focus on ongoing sources of contamination with the potential to cause recontamination. Examples of contaminant sources include:

- discharge from point sources such as industrial facility outfalls
- discharge from a POTW and CSOs
- private and public stormwater discharges (including sheet flow runoff)
- discharge of nonaqueous phase liquid (NAPL) from sediment
- overland flow from an upland (upgradient) source
- soil erosion where contaminants are present in the stream bank, riverbank or floodplain soils
- sediment transport from other sediment sources in the watershed
- contaminated groundwater discharge (such as dissolved phase and NAPL release)
- air deposition of contaminants (such as mercury from fossil fuel power plants and PAHs from particulate matter from heavily burdened traffic areas such as highways, airports, or ports)
- nonpoint source and watershed-wide sources of contamination
- over-water activities (such as fuel and product spills and ship maintenance and repair) or other incidents which release contaminants to the water body
- naturally occurring sources (such as inputs of metals or other inorganics from natural watershed sources)

The identification and control of sources of contamination is complex for several reasons:

- It is often challenging to identify all current sources of contamination, especially in large urban waterways and large watersheds with multiple point and nonpoint sources.
- High levels of uncertainty occur in extrapolating source contaminant concentrations to understand the potential for actual impact on the waterway (for instance, extrapolating a river bank, groundwater, or stormwater sample result to an in-water concentration that would expose a receptor to harmful effects).
- When evaluating offshore contamination, it is difficult to understand whether the observed contamination is associated with historical spills and releases to the sediment bed (in-water source) or whether the contamination is the result of ongoing sources of contamination.
- Sources of contamination may have a significant temporal and spatial component; for example stormwater and CSO inputs are typically episodic and have significant temporal variability. On the other hand, groundwater discharges are often associated with preferential migration pathways that exhibit significant spatial variability.

For sites in larger urban areas or watersheds that may have been affected by numerous sources, the identification, evaluation, and control of sources of contamination to the watershed is complex and requires coordination with multiple agencies and parties. For example, multiple sources areas may be undergoing investigation and remediation through multiple programs and multiple federal, state and local agencies. In addition, total maximum daily load (TMDLs) may be developed to address wastewater discharges, stormwater discharges, and nonpoint sources for watershed wide sources of toxic pollutants. In this case, coordination across a range of regulatory programs may be required so that sources are controlled sufficiently to allow sediment remedies to proceed. More information may be found in USEPA's *Handbook on Integrating Water and Waste Programs to Restore Watersheds* (USEPA 2007).

Some sources may be outside the designated sediment site boundaries and may require control on a watershed or regional basis. During the screening process, an understanding of potential off-site sources of contamination is necessary to determine the on-site background concentrations of contaminants (ITRC 2011a). These sources must be understood, particularly with regards to the extent to which they are expected to be controlled and the regulatory framework to be used to control them. The site investigation and remedy evaluation must be sufficient to determine the extent of the contamination coming onto the site and its probable effect on any actions taken at the site. A critical question is whether an action in one part of the watershed is likely to result in significant and lasting risk reduction, given the timetable for other actions in the watershed and whether a coordinated watershed-wide source control program is required. Source control activities are often broad ranging and may include cross-agency coordination throughout the watershed.

> ***On-site and Off-site Source Control***
>
> *Where sources are a part of the site, project managers should develop a source control strategy as early as possible during site characterization.*
>
> *Where sources are off site, project managers should encourage the development of source control strategies by other responsible parties or authorities and collaboratively understand those strategies. The extent to which off-site sources are expected to continue to contribute contamination at the site should be considered in establishing realistic RAOs.*

When multiple sources exist, they must be prioritized according to risk in order to determine where best to focus resources. Generally, any significant continuing site-related upland sources (including contaminated groundwater, stormwater, NAPL migration, or other releases) should be controlled in a manner and time frame compatible with the sediment remedy. Once these sources are adequately controlled, project managers can better evaluate the effectiveness of the actions and potentially refine and adjust levels of source control as warranted. In most cases, before any action is taken, project managers should consider the potential for recontamination and factor that potential into the development of RAOs and final remedy selection. If a site includes a source that could cause significant recontamination, source control measures are probably necessary as part of the response action.

If sources can be adequately controlled, re-evaluate risk pathways to see if sediment actions are still needed. On the other hand, if sources cannot be adequately controlled, the effectiveness of any sediment remedy will be limited. If sources cannot be controlled, include these ongoing sources in the evaluation of appropriate sediment actions and when defining achievable RAOs for the site.

2.4 Step 1 - Review of Site Characteristics

The first step in the remedial evaluation framework is to review the CSM to understand the relationship between sources, migration pathways, and receptors and to understand the physical conditions and contaminant properties governing exposure and risk at the site. Information presented in the CSM should support identification of the site-specific characteristics needed in the evaluation of remedial technologies. If sufficient data are not available to evaluate remedial technologies, then more information may be needed in order to effectively use the remedy selection framework (see Section 2.1, USEPA 2005a).

> **Interactive Screening Worksheet**
>
> *The ITRC web site offers an interactive Remedial Technology Worksheet.*
>
> *You can download this worksheet and use it to document site characterization activities and to determine whether additional data is necessary to properly evaluate remedial technologies based on site specific conditions.*

This guidance document provides several tools to assist in the review of site characteristics. Table 2-2 presents a summary of the types of data that may be required at contaminated sediment sites, potential approaches to obtain the data, and the implications of the data types for remedy selection. Table 2-4 identifies the key characteristics that should be included in the evaluation of each potentially applicable remedial technology, including links to applicable sections of the technology overviews.

While the list of potential site characterization needs is extensive, note that data for all of the characteristics in Table 2-2 and Table 2-4 may not be required at every site in order to use the remedy selection framework. Information needs are site specific—more complicated sites require more site characterization effort. For simple sites that are relatively quiescent, are not within urbanized areas, or cover a small area, site characterization activities should be limited to the few factors likely to govern the evaluation of remedial technologies. However, for complicated sites within dynamic hydrologic regimes, with multiple contaminant sources and site uses, and which cover a large area, a large suite of site characterization activities will be required. Ultimately, site managers must determine and document which characteristics are most relevant to each site based on the CSM. Table 2-2 and Table 2-4 should be reviewed in conjunction with the CSM to determine whether the information available is sufficient or if additional data collection is required to properly evaluate remedial technologies at your site (ITRC 2013).

The need for additional site characterization data must be balanced with the incremental value of information obtained. At some point during data collection, professional judgment can determine that the data collected are adequate to characterize the risk and select a remedy. The timing and stage of the remediation process are also important. In the early stages of a RI, less certainty exists regarding which of the detected chemicals will become COCs and will need to be addressed with a remedy. Therefore, consider the timing of site characterization aimed at risk assessment and COC determination with respect to the site characterization aimed at supporting remedy selection and design. At many sites, a phased characterization effort during the RI or an RI effort followed by a supplemental characterization during the FS stage may be appropriate. Remediation professionals must develop adequate site data to support the decisions being made during critical stages of the remediation process.

At contaminated sediment sites, it is common to conduct an RI over several years. Usually, this time is adequate to identify FS data needs before the RI is complete. Once the first phase or phases of the RI result in data that show the presence of sediment with chemical concentrations significantly above screening levels, a scope can be developed for the FS based on the results of the initial site characterization and refinement of the CSM. The information presented in this section and in Table 2-2 can be used to scope RI data collection.

2.4.1 Site Characteristics

Evaluating remedial technologies requires site-specific data that may affect a technology's performance. These data needs go beyond the data necessary to delineate the nature and extent of contamination and include information necessary to evaluate sediment stability and transport, contaminant mobility, waterway characteristics, hydrology and adjacent land and waterway use. The CSM and site geomorphology help determine the degree of site characterization required to properly evaluate remedial technologies. Understanding the relationship between contaminant sources, transport mechanisms, exposure media, and factors that control contaminant distribution and potential exposure is critical to developing a focused site characterization approach. For example, sediment transport is often controlled by infrequent, high energy events. Site characterization activities should include efforts to determine the influence of these events on contaminant transport and distribution. Site characterization needs have been divided into four main categories as detailed in Table 2-2 and as summarized below.

2.4.1.1 Physical Characteristics

Physical characteristics include the nature of the sediment bed, groundwater discharge, hydrodynamics, bathymetry and changes in the water depth over time, the presence of debris, infrastructure and other obstructions, the presence of a hard pan or bedrock within the sediment bed, water flow, and currents. This information is used to understand the distribution of the contamination, evaluate monitored natural recovery, evaluate contaminated sediments removal, understand shoreline engineering considerations, determine the placement of in situ treatment materials, and develop the design and placement of sediment caps.

2.4.1.2 Sediment Characteristics

Sediment characteristics include sediment grain size, total organic carbon (TOC) content, sediment transport properties, sediment deposition rate, the potential for resuspension and release during dredging, and a variety of other geotechnical parameters. These parameters may be used in a multiple lines-of-evidence evaluation to assess monitored natural recovery, sediment removal, the placement of in situ treatment materials, and the design and placement of sediment caps.

2.4.1.3 Contaminant Characteristics

Contaminant characteristics include the contaminant's nature, horizontal and vertical extent, mobility, bioavailability, bioaccumulation potential, persistence, and background and watershed contributions. A good understanding of these characteristics is essential in determining remediation goals and evaluating the effects of specific characteristics of site contaminants on the remedial technologies.

2.4.1.4 Land and Waterway Use Characteristics

Land and waterway use characteristics include navigation, recreational use (boating, fishing), habitat, future development activities, hydraulic manipulation, and the availability of areas for sediment management (such as dewatering) and disposal. Land and waterway use characteristics have direct bearing on the implementation of the various remedial technologies.

2.4.1.5 Munitions and Explosives of Concern

If the preliminary assessment of a site determines that munitions and explosives of concern (MECs) may be present in the sediment, special precautions must be taken. If not handled properly, MECs brought to the surface during remedial activities could present explosion risks or other severe health risks. MECs may result from 1) former military ranges used for training and testing munitions; 2) emergency disposal; 3) surplus munitions disposal in designated and undesignated areas; or 4) discharges from ammunition production or demilitarization activities.

2.4.1.6 Hyporheic Zone

The hyporheic zone is the area of sediment and porous space adjacent to a stream, river, or lake (in lakes referred to as hypolentic zone) through which surface water and groundwater readily exchange. A healthy hyporheic zone is key to a productive watershed. Characterizing the hyporheic zone is critical to the evaluation of remedial technologies and the design and implementation of monitoring programs.

Several of the site characteristics presented in Table 2-2 are directly associated with the hyporheic zone (noted with an asterisk in the table). While characterization of groundwater/surface water interactions is not necessary at all sites, these characteristics relate to the ecological functions of this zone and their protection and maintenance should be a consideration in any sediment remedial action. The exchange of groundwater/surface water, salt, brackish, or fresh water within aquatic systems often defines critical ecosystems that must be properly addressed and evaluated in risk assessments as well as in remedial decisions.

The hyporheic zone is dynamic and expands and contracts with variations in water level. The gain or loss of water from this zone therefore affects when, where, and how pore-water sampling is conducted. The hyporheic zone functions as the biological interface between groundwater and surface water. Groundwater is generally low in dissolved oxygen and enriched in inorganic solutes compared to surface water. As a result, the hyporheic zone is an active location of biogeochemical transformation of nutrients and other dissolved solutes. Additional information on the evaluation and ecological significance of the hyporheic zone can be found in reports by USEPA (2008b) and USGS (1998). The importance of this zone to community and tribal stakeholders is discussed in Section 8.0.

Characterization of the hyporheic zone should include characterization of sediment and pore-water chemistry and geochemical parameters, the rate and direction of groundwater flow over a range of water elevations, and characterization of the benthic community (including benthic toxicity and benthic community indices).

Table 2-2. Summary of site characterization needs for contaminated sediment sites

Data Type	Potential Site Characterization Approaches	Implications for Remedy Selection
Physical Characteristics		
Sediment Stability	Characterization of sediment bed to determine stability requires multiple lines of evidence. Examples of lines of evidence are: bathymetric surveys, grain size analysis, bed pins, scour chains, and geochronology cores. For complex sites, special tools such as Sedflume measurements, sediment traps, and sediment transport modeling may be needed.	Stable sediments may be conducive to monitored natural recovery if cleaner material is being deposited and not subject to net erosion. In addition, stable sediments may be more suitable for enhanced MNR and in situ treatment. Stable sediments typically require less erosion protection for capping options.
Sediment Deposition Rate	Sediment deposition rates may be estimated using sediment traps and geochronology cores. Multiple lines of evidence may be useful for developing quantitative estimates of sediment deposition, including items such as dredge records, historical bathymetry surveys, and sediment dating.	MNR generally requires the deposition of clean material over contaminated material. Areas not subject to erosion with inadequate natural sediment deposition are good candidates for enhanced MNR.
Erosion Potential of Bedded Sediments	Erosion potential may be estimated using combined Sedflume measurements, flow measurements,and hydrodynamic evaluations. Multiple lines of evidence may be useful for developing a qualitative estimate of sediment erosion potential. The evaluation of erosion potential must consider the effect of infrequent high energy events such as floods and hurricanes.	Contaminated sediments with a high resuspension potential may represent a source of downstream and water column contamination that must be addressed through remediation.
Water Depth and Site Bathymetry	Bathymetric surveys and lead-line depth measurements may be used to estimate water depth. Bathymetric features can also aid in delineation of contaminant extent. Interpretation of water depth data requires an understanding of tidal range and seasonal or longer-term patterns of water elevation. Time series bathymetry may be useful to understand sediment bed changes. See also Sediment Stability data needs.	Water depth has implications for placement of caps if a minimum water depth must be maintained and for selection of removal methods (for example, excavation, use of barge-mounted excavators versus cable arm buckets).

Table 2-2. Summary of site characterization needs for contaminated sediment sites (continued)

Data Type	Potential Site Characterization Approaches	Implications for Remedy Selection
In-Water and Shoreline Infrastructure	Physical and geophysical site surveys may be used to identify the location of docks, piers, underwater utilities, and other structures. These structures may later require an assessment of their structural integrity.	The presence of structures has a significant impact on the feasibility of various sediment remediation options such as dredging.
Presence of Hard Bottom	Hard bottom (bedrock, hard pan, coarse sediment, large cobbles, or boulders) may be identified through subsurface sediment cores and geophysical surveys.	The presence of bedrock, hardpan, large cobbles, or boulders may limit the effectiveness of dredging. Management of residuals through placement of sand cover or specialized dredging equipment may improve dredging effectiveness.
Presence of Debris	Debris surveys should be performed in urban waterways. Geophysical surveys (side scan sonar) and diver surveys (underwater photographs, metal detectors) may be used to identify underwater obstructions such as pilings and other buried debris. MEC surveys should be performed if the presence of explosives is likely.	The presence of debris has a significant impact on the feasibility and effectiveness of removal based sediment remedies. Certain debris such as pilings may be removed prior to dredging or capping activities. Debris generated residuals may be managed through the placement of sand covers or backfill following dredging activities.
Hydrodynamics	Information on flow dynamics is necessary to quantify hydrodynamics. These may include acoustic Doppler current profile (ADCP) measurements and USGS water stage and flow data. The evaluation should include an assessment of wave action, tidal forces, and wind-driven seiche potential. Use a mix of empirical and modeled results to assess the hydrodynamics of the waterway.	Hydrodynamics have a direct bearing on the evaluation of contaminant mobility, and therefore capping-based remedies and enhanced MNR remedies.
Slope and Slope Stability	Bathymetric surveys and existing navigation charts may be useful for determining river bottom slope. Identify steeply sloped areas. Geotechnical investigations may be required to evaluate slope stability.	Sediment bed slope may influence the design and construction of capping-based remedies and feasibility of removal-based remedies. Capping in several smaller lifts may be needed on steep slopes. Sloughing of clean material from side slopes during dredging may unnecessarily increase disposal volumes.

Table 2-2. Summary of site characterization needs for contaminated sediment sites (continued)

Data Type	Potential Site Characterization Approaches	Implications for Remedy Selection
Groundwater/ Surface Water Interaction *	Upland groundwater investigations and flux chamber measurements help to explain the range of rates of groundwater to surface water discharge and the potential for groundwater movement to transport subsurface sediment and groundwater contaminants to the surface sediment layer and water column. Measurement of surface water and pore-water characteristics (geochemical and contaminant compositions) may be useful for characterizing the degree of mixing between surface water and groundwater and evaluation of geochemical processes, such as degradation, within the biologically active zone. For certain contaminants (such as bioaccumulative organic compounds) or low permeability sediments, consider passive sampling devices.	Evaluation of groundwater/surface water interactions is useful for understanding groundwater source control, contaminant fate and transport, and bioavailability. Areas with high advective groundwater flux may limit the effectiveness of sediment remedies. Groundwater retention time within the sediments is important for evaluation of natural attenuation of groundwater contaminants. If capping remedies are contemplated, consider amended capping technologies (such as sorptive materials) when groundwater flux is high. The use of low permeability capping materials in areas of high groundwater flux may result in cap deformation.
Sediment and Pore-water Geochemistry, including Organic Carbon (TOC, DOC, POC)*	Characterizing sediment and pore water for a range of constituents (such as AVS/SEM, contaminant form, redox potential, and pH) may be useful for understanding contaminant fate and transport processes, biodegradation, and contaminant bioavailability.	Contaminant fate and transport and bioavailability may be useful for evaluation of MNR, enhanced MNR, in situ treatment, and capping technologies.
Sediment Characteristics		
Geotechnical Properties	Key geotechnical parameters include: bulk density, shear strength, specific gravity, water content, cohesiveness, organic content, and Atterberg limits (plastic limit, liquid limit, and plasticity index).	Geotechnical parameters have a direct effect on the feasibility of all remedial technologies for sediments. These parameters are also useful in evaluating the dewaterability of dredged sediment. Special design and construction methods are required to place cap material over low-strength sediment. Sediment strength and density are important for selection of dredging equipment.

Table 2-2. Summary of site characterization needs for contaminated sediment sites (continued)

Data Type	Potential Site Characterization Approaches	Implications for Remedy Selection
Grain Size Distribution	Characterization may be done through grain size analysis (sieve and hydrometer) or by visual inspection.	Grain size is an indicator of energy within the system and can be used to identify quiescent areas or areas where deposition is likely. A bimodal distribution of sediment sizes (for example, silt within the interstices of a gravel) can inhibit the effectiveness of removal actions if the contamination is associated with the finer, more easily suspended fraction.
Potential for Resuspension/ Release/Residual	Elutriate testing such as the dredged residual elutriate test (DRET) or standard elutriate test, as well as chemical equilibrium modeling and comparisons with case studies, can inform assessments of short-term water quality impacts.	Data may be used to evaluate releases during dredging and to estimate potential short-term and long-term impacts.
Sediment Consolidation (Pore-water Expression)	Use a consolidation test to provide engineering properties needed to calculate settlement or pore-water extraction, followed by chemical testing.	Influences extent to which dissolved contaminants may move into cap during placement and settling. Also important for assessing post-remedy elevations for habitat or navigation.
Benthic Community Structure and Bioturbation Potential*	Characterization of the benthic community through diversity and abundance surveys may be performed to determine habitat characteristics. The depth and density of bioturbation may affect contaminant mixing.	The presence of a healthy benthic community should be considered when evaluating invasive sediment remedies such as dredging and capping.
Contaminant Characteristics		
Horizontal and Vertical Distribution of Contamination	Required to understand the area and volume of sediment contamination that may require remediation and whether the surface sediments are more or less contaminated than subsurface sediments. The distribution of contamination may be used to identify areas of diffuse, widespread, low-level contamination and localized areas of high concentration.	This item is a critical element for the evaluation of all sediment remedial technologies. Exposingdeeper, more contaminated sediments by dredging may increase the risk by increasing the average contaminant concentration in surficial sediments. Can be useful to support MNR and EMNR remedies.

Table 2-2. Summary of site characterization needs for contaminated sediment sites (continued)

Data Type	Potential Site Characterization Approaches	Implications for Remedy Selection
Contaminant Type (Inorganic/ organic /UXO/size fraction)	The site characterization should determine the type of contamination present at the site (inorganic, organic, MEC, or other). While most sediment contaminants are associated with the fine-grained sediment fraction (silt and clay), some contaminants are sand-sized and larger (lead shot, UXO).	Contaminant type has a direct effect on and risk and exposure potential as well as removal strategies, sediment disposal, treatment, and biodegradation potential.
Contaminant Concentration	Analysis of all potentially impacted media for COCs can be important to understanding transport and risk pathways. Bulk sediment, surface water, pore-water, and biota tissue may be analyzed to determine contaminant concentration distribution and bioavailability of site contaminants and to develop the relationships necessary to evaluate site remedies. Depending on site size and COC distribution, characterization may identify areas of higher risk and lower risk for both human and ecological health.	Critical element for the evaluation of all sediment remedial technologies. Can help to identify pathways that the remedy must address to reduce risk. Action with more immediate results than MNR or EMNR may be preferable in areas of higher potential risk.
Exposure Pathways	The site characterization should identify the exposure pathways contributing to risk at the site and the degree of risk throughout the site.	The exposure pathway posing risk has a direct impact on the RAOs and the evaluation of remedial technologies with respect to meeting RAOs.
Presence of Source Material (such as NAPL)	Site characterization may be required to identify the presence of NAPL or other contaminant sources. Sediment cores should be evaluated to determine presence/absence of NAPL. Upland methods for identification of NAPL are mostly applicable in sediment settings.	The presence of source material will have a direct effect on releases during dredging and the effectiveness of capping, MNR, and EMNR.
Contaminant Mobility	NAPL and soluble contaminants should be identified. See also Presence of Source Material.	Critical element for the evaluation of all sediment remedial technologies. Immobile contaminants may be effectively contained below a cap.

Table 2-2. Summary of site characterization needs for contaminated sediment sites (continued)

Data Type	Potential Site Characterization Approaches	Implications for Remedy Selection
Contaminant Bioavailability and Toxicity	Measures of contaminant bioavailability and toxicity may be needed to fully assess risk at sediment sites (ITRC 2011a). TOC, AVS/SEM, toxicity tests, bioaccumulation tests, biota tissue, and pore-water analysis provide measures of bioavailability.	Bioavailability is a critical element for assessing risk and developing site cleanup levels (ITRC 2011a) and to identify areas that may contribute disproportionately to potential site risk.
Contaminant Bioaccumulation and Biomagnification Potential	Literature surveys should be performed to develop an initial understanding of the potential for COCs to bioaccumulate. Sediment/tissue pairs for benthic and small home range species and laboratory bioaccumulation testing can be conducted for site-specific bioaccumulation factors.	Key data for assessing bioavailability and developing sediment/tissue relationships to aid in the determination of sediment cleanup levels based on critical/acceptable tissue levels and to identify areas that may contribute disproportionately to site risk.
Contaminant Transformation or Degradation	Literature surveys should be performed to develop an initial understanding of the potential for contaminant transformation and degradation. Testing to develop site specific biodegradation rates may be needed.	Data may be used to support capping models and evaluate MNR.
Source Identification and Control	Develop CSM that considers sources of contamination (see Section 2.3). Identify regulatory programs and frameworks in place to control sources of contamination (such as stormwater management programs).	Effective source control is a critical component of all successful sediment remedies.
Ebullition	Perform surveys to identify areas with significant ebullition. Ebullition may include a seasonal component.	Ebullition may affect contaminant mobility and transport and may impede capping success.
Background	Characterization of natural and anthropogenic background (see Section 2.2) is critical for bioaccumulative chemicals such as PCBs, organochlorine pesticides, and dioxin. Testing may include bulk sediment, surface water, biota tissue, and pore water.	Characterization of background is critical to the evaluation of MNR and the establishment of achievable site cleanup levels and effectiveness of any remedial technology.
Land and Waterway Use Characteristics		
Watershed Characteristics and Impacts	Characterize the watershed with respect to overall land use, location relative to urban, recreational and habitat areas, and watershed-wide contaminant sources. See also Site Access and Background Data Needs.	Watershed characteristics are relevant to the evaluation of all sediment remedial technologies.

Table 2-2. Summary of site characterization needs for contaminated sediment sites (continued)

Data Type	Potential Site Characterization Approaches	Implications for Remedy Selection
Cultural and Archaeological Resources	Perform cultural resource survey as necessary pursuant to federal, state, tribal, and local environmental rules and regulations.	The presence of cultural and archaeological resources can have a direct effect on the cost and feasibility of sediment remedies and can be a significant factor limiting the feasibility of sediment removal.
Site Access (Staging, Treatment, Transport, and Disposal)	Perform surveys to identify available land that can be used for construction work area, sediment handling, and water treatment. Survey areas of deep water that could be used for confined aquatic disposal and near shore areas that could be used for confined disposal facilities. Identify potential upland disposal sites including landfills. Assess the available transportation infrastructure (roads, railroads, dock areas) that can facilitate sediment management and transport. See also Current and Anticipated Land and Waterway Use data needs.	The availability of the necessary infrastructure to manage contaminated sediments may have a significant impact on the feasibility and cost of removal-based sediment remedies. Site access can have a pronounced impact on the feasibility and cost of removal and capping-based remedies.
Current and Anticipated Waterway Use	Evaluate current and future waterway use with respect to navigation, recreation, and habitat. May require habitat surveys that focus on both water and riparian habitat. See also Current and Anticipated Land Use data needs.	Remedies must be consistent with current and anticipated waterway use. Capping in a navigation channel may require institutional controls such as regulating boat speeds to prevent propellers from disturbing the cap. The need to dredge for maintenance may preclude a channel from being capped.
Current and Anticipated Land Use	Perform surveys to identify current and anticipated land use. Incorporate stakeholder input. Include any listed legal restrictions such as LUCs. Land use should be characterized as industrial, residential, recreational, or habitat. See also Site Access and Current and Anticipated Water Way Use data needs.	Current and anticipated land use may have direct bearing on waterway use and the evaluation of sediment remedial technologies.

Table 2-2. Summary of site characterization needs for contaminated sediment sites (continued)

Data Type	Potential Site Characterization Approaches	Implications for Remedy Selection
Endangered Species and/or Habitat	Evaluate the presence of federal, state, or tribal listed species. See also Current and Anticipated Land and Waterway Use data needs. Identify predominant organisms and, in particular, any sensitive habitats and species. Define location of critical or sensitive habitat as needed.	ESA consultation may be required. May affect the feasibility of sediment remedies. Mitigation, if required, will affect project cost. Capping or removal may not be desirable if sensitive habitat will be impacted. May need to consider leaving portion of contaminated area untouched to serve as a source for species recolonization of remediated zone.
*Applies to the hyporheic zone (see Chapter 8 for stakeholder concerns; also see USEPA 2008b).		

2.5 Step 2 - Remedial Zone Identification and Mapping

Defining remedial zones delineates the overall area and volume of contaminated sediments into workable units that are subsequently considered for remediation. Identifying these units based on site-specific conditions simplifies the evaluation of remedial technologies. Zone identification may not be applicable at every site, but the concept should at least be examined at each site.

The first step in establishing remedial zones is to identify areas on a contaminant-distribution basis. The site may be further refined by considering other factors such as contaminant characteristics, sediment characteristics, physical characteristics, and land and waterway use characteristics. Because the CSM considers contaminant sources and processes that control the distribution of those contaminants, this model may be a useful tool for identifying remedial zones.

Remedial zones should not be so small that implementing remedial technologies at each zone is impractical. For relatively homogeneous sites, a single large remedial zone may be appropriate. Although other sites may be divided into multiple remedial zones, these zones are still interconnected. When choosing different remedial zones, select zones that share at least two, preferably three, common characteristics as listed in Table 2-2.

> ***Remedial Zone Identification and Mapping***
>
> *Remedial zone identification has been used at the Fox River and Grasse River Superfund Sites. At each site, contaminant concentrations in conjunction with physical and sediment characteristics were used to develop and refine remedial approaches.*
>
> *At the Fox River Site, an optimized remedial approach was incorporated into an amended record of decision. The optimized approach relied on spatial data regarding the horizontal and vertical extent of contamination, sediment bed characteristics, and the presence of nearshore structures. This data allowed site managers to determine what combination of dredging, capping, sand cover, and MNR would best achieve the RAOs for the Fox River site.*
>
> *At the Grasse River site, the river was divided into 72 longitudinal segments that were further subdivided into nearshore and main channel segments to facilitate the evaluation of remedial action alternatives. The nearshore and main channel portions of the site comprise two fundamentally different zones based on habitat, contaminant levels, and sediment bed characteristics. The longitudinal segments allowed the evaluation of various reaches based on contaminant concentration, flow characteristics, and the potential for ice scour.*

2.5.1 Remedial Zone Identification

Remedial zones represent areas within a site where characteristics are sufficiently different to warrant consideration of different remedial approaches. Zones should first be identified based on the distribution of contamination and preliminary remedial goals (PRGs). These zones should be further refined based on site-specific information relevant to the evaluation of remedial technologies. For example, a larger area of sediment contamination may be broken into separate areas based on the presence or absence of debris, the stability of the sediment bed, and contaminant mobility. For smaller sediment sites, the area of contamination may be relatively homogenous with respect to site characteristics. At large complicated sediment sites, however, dividing the site into specific remedial zones will facilitate the focused evaluation of remedial technologies and the development, screening, and evaluation of remedial action alternatives.

Remedial zones can be developed systematically using the following procedure:

1. Consider the type and distribution of contamination, focusing on those chemicals that pose unacceptable risks to human health and the environment at the site (COCs, described in the risk assessment). These contaminants are expected to be addressed by the site remedy (USEPA 2005a). It may be possible to focus on a limited set of COCs that are the primary risk drivers, if it can be demonstrated that remediation of the risk drivers results in acceptable overall risk reduction at the site. PRGs, or multiples of the PRG, may be used when mapping contaminant distribution in order to identify those areas that present the greatest risk and exceed applicable sediment standards. Classify sites initially into three areas: action areas, no

action areas, and action undetermined areas that cannot be classified based on available data (Bridges, Nadeau, and McCulloch 2012a).

2. Determine whether it is warranted to further divide the site into multiple remedial zones, based on factors other than contaminant distribution. Site complexity dictates the number of zones needed. Identify other characteristics for mapping additional zones based on site-specific data. For example, in highly urbanized river systems, sites may be subdivided into remedial zones based on the presence and absence of debris, erosion and deposition potential, the presence or absence of NAPL sources and the ability to control these sources, and whether the adjacent land use is recreational or industrial.

2.5.2 Tools for Remedial Zone Mapping

Remedial zones should be mapped accordingly using spatial analysis tools. Although a range of mapping approaches are available, the geographic information system (GIS) is particularly useful for mapping a range of site characteristics as individual layers and using these layers to identify areas with similar characteristics. These maps should capture the distribution of contamination as well as the relevant physical, sediment, and land and waterway use characteristics.

Chemical concentration data require other mapping tools to convert point data into maps. Increasingly, various interpolations and statistical approaches are being used to map contaminant distributions. Examples include Theissen polygons, interpolation tools such as nearest neighbors, and surface weighted average concentrations (SWACs). These tools provide a means to integrate analytical data with the CSM and identify areas that may require remediation. The reliability of the resulting maps that integrate analytical data and physical layers should be quantified using empirical methods such as cross validation or, more formally, using geostatistical methods for error analysis.

2.5.3 Identifying Early Action Candidate Areas

Areas of particularly elevated surficial contaminant levels that contribute disproportionately to site risks should be identified as potential early action areas. In general, early action areas are those areas where active remediation may be used to rapidly reduce risk, prevent further contaminant migration to less affected areas, and accelerate achievement of RAOs. Other candidates for early action are areas where stakeholders agree on the need for active remediation as soon as is practical. Early action may also be appropriate for areas that are essential for survival of threatened and endangered species or must be protected for their historical value. Early action areas may be remediated using a streamlined evaluation process (for example, focused FS or EE/CA). The management of these areas should be consistent with long-term management of the site and should consider the potential for the area to become recontaminated following early action implementation.

2.6 Step 3 - Screening of Remedial Technologies

To simplify this screening step, questions are included as part of the remedy selection framework to help conduct an initial screening assessment (Table 2-3) of MNR, EMNR, in situ treatment, conventional capping, amended capping, and excavation and dredging. For the purposes of technology screening, the evaluation should focus on “technology types” as described in USEPA guidance (1988; 2005a). Note that USEPA (2005a) refers to these technologies (as used in this guidance) as "remedial approaches" or "remedial alternatives." Consider "technology process options" during the development of remedial action alternatives. The detailed and comparative evaluation of alternatives is typically performed on a "representative process option."

Screening Terminology

General response actions describe those actions that will satisfy the RAOs. For contaminated sediment sites, general response actions include treatment, containment, excavation, disposal, MNR, EMNR, institutional controls or a combination of these.

Technology type *refers to general categories of technologies, such as dredging, conventional capping, amended capping, physical treatment, MNR, or EMNR.*

Technology process option *(process option) refers to specific processes within each technology type. For example, at contaminated sediment sites, the technology process option includes hydraulic dredging, mechanical dredging, sand cap, low permeability cap, carbon amendments, organophilic clay amendments, thin-layer capping, MNR, or fish consumption advisories.*

Representative process option *refers to a particular option used for comparative analysis. For the evaluation of remedial action alternatives, representative process options are typically evaluated to simplify the subsequent development and evaluation of alternatives without limiting flexibility during remedial design.*

The screening questions may be used to evaluate and screen remedial technologies from further consideration on a zone by zone basis. A worksheet for performing this preliminary screening is presented in Table 2-3. The worksheet is designed to assist in evaluating site-specific information to determine whether certain conditions are present at the site (or within a zone) that may eliminate one or more less effective remedial technologies from further consideration. ITRC also offers an interactive version of this worksheet for download and use.

Interactive Screening Worksheet

An interactive worksheet version of Table 2-3 is available on the ITRC website.

This worksheet can be downloaded, saved to your local drive, and completed with specific information for your site.

For many sites, the existing data or site specific conditions may make it difficult to determine with certainty if a particular condition is present; a column has been provided in the worksheet for the degree of confidence that exists for a given condition. Examples of the types of uncertainties or assumptions that may be captured in this column of Table 2-3 include:

- unknowns regarding terrestrial factors that may affect the use of a particular technology, such

as the degree of source control expected and changes in land-use
- the potential for an action in another part of the site or within a zone to cause a technology to become applicable in the zone being evaluated (for example, for moderate concentrations, removal of an upstream hotspot could make MNR viable in downstream zones)

To screen technologies effectively, additional site-specific data may be needed to determine whether a condition exists. Additional data needs may be evaluated based on professional judgment. Generally, if several of the conditions listed for a remedial technology in Table 2-3 are not present, and a high degree of confidence exists for the data, then the remedial technology for that zone may be excluded from the detailed evaluation of remedial technologies in Step 4. Note that the questions presented in Table 2-3 may not be sufficient to screen remedial technologies in all cases. Additional screening of remedial technologies may take place based on the TAGs and more detailed evaluation of remedial technologies described in Step 4.

Table 2-3. Initial screening of remedial technologies worksheet (example)

Conditions That May Include a Remedial Technology for Further Consideration	Condition Present?	Confidence (High, Medium, Low)?	Comment
Monitored Natural Recovery			
Concentrations of COCs in sediment and tissue are decreasing at a rate to meet RAOs within an acceptable time frame.			
Low concentrations (relative to cleanup goals) are present over large areas at the site.			
Net sediment deposition rates are adequate to consider natural sedimentation as a reasonable alternative to meet RAOs.			
Evidence shows that contaminants are degrading to less toxic constituents, the COCs are known to degrade, or natural sequestration is making contaminants less biologically available.			
Dispersion of contaminants is occurring quickly enough to meet RAOs in an acceptable time frame and is consistent with RAOs (for example, if RAOs allow for off-site migration of contaminants).			
Based on these conditions, should MNR be retained for further consideration? (Yes/No)			

Conditions That May Include a Remedial Technology for Further Consideration	Condition Present?	Confidence (High, Medium, Low)?	Comment
Enhanced Monitored Natural Recovery			
Enhancing one or more MNR processes (such as accelerating the sedimentation rate by applying a thin-layer cap to reduce the concentration of the COC in the bioavailable layer) is expected to reach RAOs within a reasonable time frame.			
Enhancing one or more MNR processes is compatible with current and future land and waterway use.			
Characteristics of the site do not inhibit or prevent placement of material.			
Sediment conditions are stable enough for the emplaced material to remain in place to be effective.			
Based on these conditions, should enhanced MNR be retained for further consideration? (Yes/No)			
In situ Treatment			
COCs are amenable to treatment, and treatment can be achieved in a time frame consistent with the RAOs.			
Conditions are such that the amount of in situ treatment amendments needed is considered practical, stable, and consistent with the RAOs.			
Conditions are such that in situ treatment amendments can be delivered effectively (for instance, debris or other factors do not prevent mixing).			
In situ treatment amendments are available at the quantity required.			
Based on these conditions, can in situ treatment be retained for further consideration? (Yes/No)			
Conventional Capping			
The cap will effectively isolate the COCs for an adequate time frame (with monitoring and maintenance).			
Capping is compatible with current and future land and waterway use. Physical conditions (for example, debris, slope, load bearing capacity) are such that they allow establishing an effective cap.			

Conditions That May Include a Remedial Technology for Further Consideration	Condition Present?	Confidence (High, Medium, Low)?	Comment
Based on these conditions, can physical capping be retained for further consideration? (Yes/No)			
Amended Capping			
Amended cap will effectively treat COCs (for example, isolate or reduce the bioavailability), is compatible with future site use expressed in the RAOs, and is expected to function for an adequate time frame (with monitoring and maintenance).			
Amended capping is compatible with current and future land and waterway use.			
Physical conditions (debris, slope, load bearing capacity, and others) allow an effective cap to be established.			
Based on these conditions, can amended capping be retained for further consideration? (Yes/No)			
Excavation			
Site conditions (such as water level fluctuation, water depth, ability to install hydraulic barrier and/or sheet piles, and waterway configuration) are amenable to dry excavation.			
The contaminant distribution is limited in extent so that it can be isolated by the installation of hydraulic barriers such as an earthen berm, sheet piles, coffer dams, or stream re-routing.			
Removal is practical; for instance, the site does not have extensive structures or utilities.			
Dredged material disposal sites and processing or treatment facilities are available.			
Based on these conditions, can excavation be retained for further consideration? (Yes/No)			
Dredging (wet)			
Sediments are shallow enough to implement environmental dredging with existing technology (approximately less than 100 ft).			
Dredging is practical; for instance, the site does not have extensive debris, structures, hard bottom, or utilities.			

Conditions That May Include a Remedial Technology for Further Consideration	Condition Present?	Confidence (High, Medium, Low)?	Comment
Water quality effects of dredging are expected to be acceptable.			
Areas are available for staging, handling, dewatering, disposal, and processing and treatment of the dredge material.			
Based on these conditions, can dredging be retained for further consideration? (Yes/No)			

2.7 Step 4 - Evaluation of Remedial Technologies

In Step 4, detailed evaluations of remedial technologies retained after the initial screening step are conducted using site-specific information to identify the most favorable technologies. Based on these evaluations, additional remedial technologies may be eliminated.

Following links to sections of the technology overviews and returning allows you to populate the Table 2-5 worksheet.

Use the characteristics listed in Table 2-4 and described in the technology overviews to identify the remedial technologies applicable for each remedial zone. Step 4 includes technology assessment guidelines and a weight-of-evidence approach to help determine which remedial technologies are most favorable based on the site-specific conditions listed in Table 2-4 and evaluated with the interactive spreadsheet described in Step 3 (Table 2-5). Table 2-4 lists the physical, sediment, contaminant, and land and waterway use characteristics used to establish the applicability of each of the technologies (MNR, EMNR, in situ treatment, conventional capping, amended capping, dredging and excavation). Each cell corresponds to a characteristic and technology, and is linked to a section (indicated by the section number) of the technology overview that describes the relevance of the characteristic. Each cell also contains a ranking of importance of each characteristic for specific technologies:

- H = Critical: This characteristic is critical to determining the applicability of the specific technology.
- M = Contributing: This characteristic is not critical to determining the applicability of a specific technology but may help determine the effectiveness of the technology.
- L = Unimportant: This characteristic is not a consideration in evaluating whether a specific technology is applicable at a site.

By evaluating only the critical characteristics, site managers can determine whether a technology is applicable to the conditions at the site. Additional information (contributing) is important in evalutating the effectiveness of the technology according to other remedial parameters (such as RAOs) at the site.

2.7.1 Technology Assessment Guidelines

TAGs are a key component of this guidance and can help to evaluate the applicability of remedial technologies retained after the screening step. The TAGs offer a range of sample site conditions that may support the effective application of individual remedial technologies. These TAGs must be used within a weight-of-evidence approach and as an aid to remedy selection (but not the only selection approach). TAGs are indicated in text with and icon followed by the rule highlighted in the text: *TAGs are quantitative or qualitative guidelines based on simplified models, relationships, and experience that help to evaluate the potential effectiveness and feasibility of remedial technologies using site-specific information. TAGs are intended to be used as rough, practical guidelines in a weight-of -evidence approach, not as pass/fail criteria.*

The TAGs provide estimated ranges for site characteristics that are conducive to individual remedial technologies, as well as unfavorable conditions and limitations for the optimum application of technologies. TAGs are intended to highlight where certain conditions could be used within a weight-of-evidence approach to aid selection. Subject to professional judgment, TAGs may be given different weights based on their importance or deviations in the site-specific conditions from the preferred ranges. TAGs applicable to MNR, EMNR, in situ treatment, conventional and amended capping, and removal (by dredging or excavation) have been provided where possible. TAGs are indicated with a symbol in Table 2-4 and are linked to additional explanations within the technology overviews. For example, TAGs have been provided for slope requirements (4.4.1.8) and groundwater flux ratesto assess whether conventional capping might be an effective remedial technology at a site. The TAGs provide a means for comparing site data to ranges derived from field experience, and are intended to act as an aid in evaluating the applicability of technologies in relation to site-specific data.

Although the TAGs may be used singly, they are intended to be used in combination with other TAGs and lines of evidence, since many of the TAGs are interrelated. Multiple TAGs that support one technology over another offer a higher degree of confidence in the results of the technology evaluation. In addition, certain limitations identified through application of the TAGs can be addressed by applying remedial technologies in combination with one another. For example, water depth limitations may prevent placement of sediment caps; however, dredging may be conducted prior to cap placement to overcome this limitation.

Table 2-4. Summary of key site characteristics for remedial technologies and links to TAGs

Characteristic	Monitored Natural Recovery		In situ Treatment	Capping		Removal		
	MNR	EMNR		Conventional Capping	Amended Capping	Dredging		Excavation
						Hydraulic	Mechanical	
A. Physical Characteristics								
Sediment Stability	TAG H 3.4.1.1	TAG H 3.4.1.1	TAG H 4.4.1.5	TAG M 5.4.1.5	TAG M 5.4.1.5	L 6.4.1.1		L 6.4.1.1
Sediment Deposition Rate	TAG H 3.4.1.2	TAG H 3.4.1.2	TAG M 4.4.1.4	TAG M 5.4.1.2	TAG M 5.4.1.2	L 6.4.1.2		L 6.4.1.2
Erosional Potential of Bedded Sediments	TAG H 3.4.1.3	TAG H 3.4.1.3	TAG H 4.4.1.10	TAG M 5.4.1.1	TAG M 5.4.1.1	TAG L 6.4.1.3		L 6.4.1.3
Water Depth, Site Bathymetry	TAG M 3.4.1.4	TAG M 3.4.1.4	TAG H 4.4.1.9	TAG H 5.4.1.3	TAG H 5.4.1.3	TAG H 6.4.1.4	TAG H 6.4.1.4	TAG H 6.4.1.4
In-Water and Shoreline Infrastructure	M 3.4.1.5	M 3.4.1.5	TAG M 4.4.1.6	TAG M 5.4.1.4	TAG M 5.4.1.4	H 6.4.1.5	H 6.4.1.5	H 6.4.1.5
Presence of Hard Bottom	M 3.4.1.6	M 3.4.1.6	L 4.4.1.7	L	L	TAG H 6.4.1.6	H 6.4.1.6	TAG H 6.4.1.6
Presence of Debris	L 3.4.1.6	L 3.4.1.6	M 4.4.1.7	TAG M 5.4.1.4	TAG M 5.4.1.4	TAG H 6.4.1.6	TAG H 6.4.1.6	M 6.4.1.6
Hydrodynamics	H 3.4.1.7	H 3.4.1.7	TAG H 4.4.1.3	TAG H 5.4.1.1	TAG H 5.4.1.1	TAG M 6.4.1.7		M 6.4.1.7
Slope and Slope Stability	TAG M 3.4.1.8	TAG M 3.4.1.8	TAG H 4.4.1.8	TAG H 5.4.1.5	TAG H 5.4.1.5	TAG M 6.4.1.8	TAG M 6.4.1.8	M 6.4.1.8
Groundwater/Surface Water Interaction	TAG H 3.4.1.9	H 3.4.1.9	TAG H 4.4.1.1	TAG H 5.4.1.7	H 5.4.1.7	L 6.4.1.9		TAG M 6.4.1.9
Sediment and Pore-Water Geochemistry	M 3.4.2.4	M 3.4.2.4	H 4.4.2.3	M 5.4.1.8	H 5.4.1.8	L 6.4.1.10		L 6.4.1.10
B. Sediment Characteristics								
Geotechnical Properties	M 3.4.2.1	M 3.4.2.1	TAG M 4.4.2.2	TAG H 5.4.2.1	TAG H 5.4.2.1	TAG H 6.4.2.1	TAG H 6.4.2.1	TAG M 6.4.2.1
Grain Size Distribution	L 3.4.2.2	TAG L 3.4.2.2	M 4.4.2.1	L	L	M 6.4.2.2	L 6.4.2.2	L 6.4.2.2

Table 2-4. Summary of key site characteristics for remedial technologies and links to TAGs (continued)

Characteristic	Monitored Natural Recovery: MNR	Monitored Natural Recovery: EMNR	In situ Treatment	Capping: Conventional Capping	Capping: Amended Capping	Removal: Dredging: Hydraulic	Removal: Dredging: Mechanical	Removal: Excavation
Potential for Resuspension/ Release/Residual	L 3.4.2.3	L 3.4.2.3	M 4.4.2.4	M 5.4.1.1	M 5.4.1.1	H 6.4.2.-3	H 6.4.2.3	H 6.4.2.3
Sediment Consolidation (Pore-Water Expression) Liquefaction	L 3.4.2.4	L 3.4.2.4	M 4.4.2.3	H 5.4.1.6	H 5.4.1.6	L 6.4.2.4		L 6.4.2.4
Benthic Community Structure and Bioturbation Potential	M 3.4.2.5	M 3.4.2.5	M 4.4.2.5	H 5.4.2.3	H 5.4.2.3	L 6.4.2.5		L 6.4.2.5
C. Contaminant Characteristics								
Horizontal and Vertical Distribution of Contamination	H 3.4.3.1	H 3.4.3.1	H 4.4.3.2	H 5.4.3.1	H 5.4.3.1	H 6.4.3.1		H 6.4.3.1
Contaminant Type (Inorganic/Organic /UXO/Size Fraction)	H 3.4.3.2	H 3.4.3.2	H 4.4.3.1	M 5.4.3.2	M 5.4.3.2	H 6.4.3.2		H 6.4.3.2
Contaminant Concentrations (Risk Reduction Required)	H 3.4.3.3	H 3.4.3.3	H 4.4.3.3	H 5.4.3.1	H 5.4.3.1	H 6.4.3.3		H 6.4.3.3
Exposure Pathways	H 3.4.3.4	H 3.4.3.4	H 4.4.3.12	M 5.4.3	M 5.4.3	L 6.4.3.4		L 6.4.3.4
Presence of Source Material (such as NAPL)	H 3.4.3.5	H 3.4.3.5	H 4.4.3.8	H 5.4.3.3	H 5.3.2	H 6.4.3.-5	H 6.4.3.5	H 6.4.3.5
Contaminant Mobility	H 3.4.3.6	H 3.4.3.6	H 4.4.3.4	H 5.4.3.3	M 5.4.3.3	M 6.4.3.6		L 6.4.3.6
Contaminant Bioavailability	H 3.4.3.7	H 3.4.3.7	H 4.4.3.5	L	L	L 6.4.3.7		L 6.4.3.7
Contaminant Bioaccumulation and Biomagnification Potential	H 3.4.3.8	H 3.4.3.8	H 4.4.3.6	L	L	L 6.4.3.8		L 6.4.3.8
Contaminant Transformation/Degradation	H 3.4.3.9	H 3.4.3.9	H 4.4.3.7	M 5.4.1.8	M 5.3.2	L 6.4.3.9		L 6.4.3.9
Source Identification and Control	H 3.4.3.5	H 3.4.3.1-0	H 4.4.3.9	H 5.4.3.3	H 5.4.3.3	H 6.4.3.10		
Ebullition	L 3.4.3.1-1	L 3.4.3.1-1	M 4.4.3.10	M 5.3.1	M	L 6.4.3.11		L 6.4.3.11

Table 2-4. Summary of key site characteristics for remedial technologies and links to TAGs (continued)

Characteristic	Monitored Natural Recovery		In situ Treatment	Capping		Removal		
	MNR	EMNR		Conventional Capping	Amended Capping	Dredging		Excavation
						Hydraulic	Mechanical	
Background	H 3.4.3.1-2	H 3.4.3.1-2	H 4.4.3.11	H 5.4.3.4	H 5.4.3.4	H 6.4.3.12		H 6.4.3.12
D. Land and Waterway Use Characteristics								
Watershed Sources and Impacts	H 3.4.4.1	H 3.4.4.1	H 4.4.4.1	H 5.4.4.1	H 5.4.4.1	H 6.4.4.1		H 6.4.4.1
Cultural and Archaeological Resources	L 3.4.4.2	M 3.4.4.2	M 4.4.4.2	M 5.4.4.2	M 5.4.4.2	H 6.4.4.2		H 6.4.4.2
Site access (Staging, Treatment, Transport, Disposal)	M 3.4.4.3	M 3.4.4.3	M 4.4.4.3	H 5.4.4.3	H 5.4.4.3	H 6.4.4.3	H 6.4.4.3	H 6.4.4.3
Current and Anticipated Waterway Use	M 3.4.4.4	M 3.4.4.4	M 4.4.4.4	L	L	H 6.4.4.4	H 6.4.4.4	H 6.4.4.4
Current and Anticipated Land Use	L 3.4.4.5	L 3.4.4.5	L 4.4.4.5	L	L	M 6.4.4.5	M 6.4.4.5	M 6.4.4.5
Presence of Unique or Sensitive Endangered Species and/or Habitat	M 3.4.4.6	M 3.4.4.6	H 4.4.4.6	H 5.2	H 5.2	H 6.4.4.6		H 6.4.4.6

2.7.2 Using the Remedial Technology Evaluation Worksheet

Table 2-5 presents an example of the remedial technology evaluation worksheet (also included with the interactive worksheet available for download) that should be populated with a summary of site-specific characteristics and implications for remedial technology evaluation. This worksheet helps in determining the remedial technologies that are most favorable for a remedial zone based on an evaluation of site-specific data under each of the characteristic categories. Information on the physical, sediment, contaminant, and land and waterway use characteristics should be considered. For example, information on sediment stability should be evaluated to determine whether MNR is expected to be effective within a given remedial zone. Results from Step 3 should also be incorporated into the worksheet, if desired, to document the reasons why a technology was not retained for further evaluation. A separate worksheet should be completed for each remedial zone at the site.

Technologies that are determined to be the most favorable based on this multiple lines-of-evidence approach should be used in the next step to develop remedial action alternatives. Note that implementing an action in one zone of the site may affect another zone of the site. For example, the placement of capping material in one zone may change flow characteristics in a downstream zone, or the active remediation of upstream contaminant sources in one zone may facilitate MNR in downstream zones.

Table 2-5. Remedial technology evaluation worksheet (example)

<table>
<tr><th rowspan="2">Zone</th><th rowspan="2">Site Characteristics</th><th colspan="2">Monitored Natural Recovery</th><th rowspan="2">In Situ Treatment</th><th colspan="2">Capping</th><th colspan="2">Removal</th></tr>
<tr><th>MNR</th><th>EMNR</th><th>Conventional Capping</th><th>Amended Capping</th><th>Dredging</th><th>Excavation</th></tr>
<tr><td rowspan="4">1</td><td>Physical Characteristics</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Sediment Characteristics</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Contaminant Characteristics</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Land and Waterway Use Characteristics</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="4">2</td><td>Physical Characteristics</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Sediment Characteristics</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Contaminant Characteristics</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Land and Waterway Use Characteristics</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="9">Note: Download this worksheet in order to document the qualitative and quantitative rationale used to evaluate the various site characteristics for each remedial zone for the remedial technologies presented (or those that were retained after Step 3). A separate worksheet should be completed for each zone created for a site.</td></tr>
</table>

2.8 Step 5 - Development of Remedial Action Alternatives

Based on the results of the remedial technology evaluation described in Step 4, remedial action alternatives should be developed based on those technologies deemed to be most favorable for site-specific conditions. Remedial action alternatives are expected to incorporate combinations of remedial technologies either in different zones of the same site or in combination within a single zone of a site. In cases where combined technologies will be applied in the same zone, the focus should be on the technology or technologies that contribute most to risk reduction. For example, if the greatest risk reduction is achieved by contaminant isolation through capping, but material must be removed to allow capping to be implemented, then the primary technology is capping. Conversely, if the greatest risk reduction is achieved through removal, but the placement of clean sand will be used to control residuals generation during dredging, then the primary technology is removal.

A range of target cleanup levels are usually evaluated in the FS in order to understand the relationship between long-term effectiveness and cost. A collection of alternatives that are favorable for site remediation can be formulated using the remedial technology evaluation worksheet as a foundation, coupled with the principles described below for development of remedial action alternatives. Step 6 includes a process for evaluating these alternatives.

2.8.1 Principles for Development of Remedial Action Alternatives

The development of RAOs is based on a wide range of factors that are sometimes in conflict with one another. The following set of general principles should be considered by individuals, agencies, PRPs, or any other interested party when considering remedial action alternatives for meeting RAOs.

2.8.1.1 Focus on RAOs and Net Risk Reduction

Remedial action alternatives should be developed and evaluated based on their ability to achieve RAOs. In most cases, meeting RAOs depends on the degree of net risk reduction achieved by a chosen remedial action alternative in a given time frame. Net risk reduction takes into account long-term risk reduction as well as short-term implementation risks. When considering long-term risk reduction, the amount of contaminated material left in place may be a factor that influences uncertainty in long term projections of risk reduction, the adequacy of controls to manage material left in place, and long-term remedy effectiveness and permanence. Net risk reduction should consider predicted declines in sediment concentration following completion of active remediation and further into the future if MNR is expected to be a component of the site remedy.

Measures of risk reduction should also consider the RAOs developed for the site. For example, if reduction of contaminants in fish tissue levels is the RAO, net risk reduction should be measured through predicted declines in fish tissue levels in conjunction with predicted declines in sediment contamination. Short-term risk reduction focuses on risks caused by remedy implementation (such as releases during dredging or capping activities), which can be minimized by engineering controls (such as installing sheet pile walls to minimize releases to the surrounding water bodies). Long-term risk reduction may be achieved by removing contamination, permanently isolating contamination, or permanently reducing the bioavailability of the contaminants. Whatever remedy is selected, monitoring (see Chapter 7) is required to document that RAOs have been met or are on schedule with predictions.

The key factor for evaluating sediment remedies is the degree to which the remedy will meet the RAOs established for the site. Under CERCLA, all remedies must achieve the threshold criteria of protectiveness and compliance with ARARs. RAOs are narrative goals for protection of human health and the environment. Ambient background levels that limit remedy effectiveness should also be considered in the establishment of RAOs. Bridges, Nadeau, and McCulloch (2012a) note that "the primary objective of an optimized risk management process is to focus the project from the very beginning, on developing and implementing solutions for managing risks posed by the site."

Consistent with USEPA guidance (USEPA 2005a), RAOs should be linked to measurable indicators of risk reduction (for instance, declines in fish tissue concentration) and long term effectiveness monitoring should be designed to measure the degree of RAO attainment. Developing a common vision for what the sediment remedy is expected to achieve, including reaching consensus among all stakeholders on the RAOs, can facilitate the remedy selection process.

2.8.1.2 Balance Short-term Impacts with Long-term Risk Reduction and Permanence

Contaminated sediment remedies often require consideration of short-term impacts associated with remedy implementation against long-term risk reduction and permanence. Sediment remedies that include dredging or capping as primary elements tend to have greater short term impacts to aquatic life and habitat than remedies that are based on EMNR and in situ treatment. These tradeoffs must be recognized and considered in the evaluation of remedial action alternatives. In addition, the costs of ongoing operation and maintenance and long-term monitoring must also be incorporated into the evaluation of alternatives.

2.8.1.3 Address In-Water Sources

Assuming that primary or upland sources have been controlled (Section 2.2) or will be addressed in the near future by separate source control efforts, address in-water sources during the remedial action alternative development process. In-water sources may be considered secondary sources at locations where contaminants from primary or upland sources have accumulated in the sediments. These sources are either sufficiently mobile or unstable enough that they may represent a source for contaminating other areas. Highly contaminated sediment, acting as a secondary source of contamination to surrounding sediment and surface water, should be targeted for active remediation that removes, controls, or permanently isolates the source of contamination. In-sediment source areas should be targeted for early actions to expedite risk reduction. Failure to address secondary source areas may result in more widespread contamination and a failure of a remedy’s long-term effectiveness.

2.8.1.4 Acknowledge Uncertainty

Because of the complexity of contaminated sediment sites and because RAOs are often tied to media other than sediment (such as reducing fish, plant or animal tissue levels to acceptable levels), uncertainty exists in the degree to which a remedial action alternative will achieve the RAOs. Uncertainty should be recognized, documented, and considered in the alternative development process, but should not be used as a basis for not taking an action or evaluating an option. This concept is embedded in Principle 15 of the Rio Declaration (1992 United Nations Conference on Environment and Development, or “Earth Summit”), which states in part:

> “Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

Uncertainty associated with sediment remedial actions is often addressed through an adaptive management process as documented by the National Research Council (2007b), which states:

> "At the largest sites, the time frames and scales are in many ways unprecedented. Given that remedies are estimated to take years or decades to implement and even longer to achieve cleanup goals, there is the potential—indeed almost a certainty—that there will be a need for changes, whether in response to new knowledge about site conditions, to changes in site conditions from extreme storms or flooding, or to advances in technology (such as improved dredge or cap design or in situ treatments). Regulators and others will need to adapt continually to evolving conditions and environmental responses that cannot be foreseen.
>
> These possibilities reiterate the importance of phased, adaptive approaches for sediment management at megasites. As described previously, adaptive management does not postpone action, but rather supports action in the face of limited scientific knowledge and the complexities and unpredictable behavior of large ecosystems."

Additionally, USEPA (2005a) encourages project managers to:

> "…use an adaptive management approach, especially at complex sediment sites to provide additional certainty of information to support decisions…project managers should develop a conceptual site model that considers key site uncertainties. Such a model can be used within an adaptive management approach to control sources and to implement a cost-effective remedy that will achieve long-term protection while minimizing short-term impacts."

2.8.1.5 Assess Cost Effectiveness

The National Contingency Plan states that "each remedial action selected shall be cost-effective, provided that it first satisfies the threshold criteria of protectiveness and compliance with ARARs." The NCP further states that a remedy is considered cost effective if its costs are proportional to its overall effectiveness. Cost effectiveness is determined by comparing overall effectiveness (defined as long-term effectiveness and permanence, reduction of toxicity, mobility, or volume through treatment, and short-term effectiveness) to cost.

The development of remedial action alternatives should focus on cost effective remedies that achieve the RAOs through a combination of remedial technologies that are determined most effective based on site-specific conditions. For many sites, MNR will be a component of the sediment remedy due to low sediment contaminant concentration. For instance, a cost effective remedy for a site may be achieved through effective primary source control, targeted remediation to address secondary source areas, and MNR in remaining areas of the site, provided that RAOs can be met within an acceptable time frame. Cost, as balanced against overall effectiveness, plays a key role in risk management. As a result, cost should be considered when developing remedial action alternatives. The evaluation of cost is considered further as part of Step 6.

2.8.1.6 Consider Risk Management

Risk management represents a balancing of the costs and benefits of available remedial action alternatives. Because of the complexity of contaminated sediment sites and the uncertainty regarding the ability of sediment remedies to achieve the RAOs, risk management and adaptive management approaches should be considered to facilitate development of remedial action alternatives that are protective and cost effective.

Key components of any risk management strategy to consider during the development of remedial action alternatives include the following:

- sufficient site characterization to support remedial decision-making
- the results of the risk assessment, including its uncertainties, assumptions, and level of resolution
- consideration of potential adverse effects posed by residual levels of site contaminants
- consideration of potential adverse effects posed by the remedial actions themselves
- source control measures to prevent recontamination
- aggressive management of contaminated sediment source areas (secondary sources) such that long term recovery can occur through natural processes
- baseline, construction, and post-remediation monitoring
- knowledge of adaptive management tools available to ensure long-term protectiveness despite uncertainty in remedy performance
- understanding how the sediment remediation project fits into overall watershed goals including control of ongoing sources through regulatory and voluntary mechanisms and future use of the water body and adjacent properties.

At many sediment sites, uncertainty exists regarding the proposed remedy's ability to achieve the remedial action alternatives. As a result, the use of adaptive management strategies should be considered to allow remedies to proceed despite these uncertainties. A key component of adaptive management is long-term effectiveness monitoring to determine the degree of progress towards remedial goals. Other components include administrative tools such as ROD amendments, explanations of significant differences (ESDs), and specific contingencies such as additional remedial and source control measures with regulatory triggers for implementing these measures.

2.8.2 Assembling Remedial Action Alternatives

Based on the principles described above, remedial technologies that are considered most favorable based on site-specific characteristics (as documented in the remedial technology evaluation worksheet, Table 2-5), should be assembled into remedial action alternatives.

Remedial action alternatives should be developed by combining the various technologies that were identified as being favorable for each remedial zone into a comprehensive suite of technologies to achieve the goals established for the entire site. Remedial technologies may need to be used in combination across remedial zones to maximize effectiveness. For example, MNR in one zone may not be effective without active remediation to address potential sources, such as an adjacent or upstream high concentration zone.

Remedial alternatives typically include a "no action" alternative, an alternative that is based on a combination of the least intrusive technologies retained for all remedial zones, and sequential alternatives that include more aggressive remedial approaches in remedial zones where risks are greater. The time frame to achieve remedial goals is longer where there is uncertainty about the long-term effectiveness. Remedial action alternatives should be developed so that net risk reduction benefits are maximized, while complexity and costs of implementing the remedy are minimized. Any remedy that does not remove or otherwise sequester persistent contaminants from the sediment should consider the costs of long-term monitoring and maintenance against the costs of removal.

Strategies for remedial action alternatives are presented below. This list is not exhaustive, but rather is intended to provide insight into the process necessary for development of viable remedial action alternatives for a site:

- No Action Alternative. This approach is the baseline case, recommended for inclusion as a basis for comparison for all other developed remedial action alternatives.
- Monitored Natural Recovery and Enhanced Monitored Natural Recovery. MNR and EMNR should be considered for large areas with lower levels of contamination that are reasonably expected to decline in conjunction with active remediation of high risk and contaminated source areas. MNR and EMNR may also be preferred in areas where ESA species are located, areas of high value habitat, or areas where historical or cultural artifacts are likely to be present. Sediment areas that are not expected to recover within a reasonable time frame but are otherwise stable (such as those not subject to high shear forces) should be targeted for EMNR.
- Active Remediation of High Risk and Source Areas. High risk and contaminated sediment source areas that are not typically amenable to monitored natural recovery should be targeted for active remediation that permanently removes, destroys, detoxifies, or isolates the sediment contamination. Active remediation is expected to be one, or a combination, of in situ treatment (Chapter 4), capping (Chapter 5), and removal (Chapter 6).
- Institutional Controls and Long-Term Monitoring. Long-term monitoring is generally required to monitor the effectiveness of all sediment remedies. For alternatives that may take a long period of time to achieve RAOs, institutional controls as well as long-term monitoring will likely be required.

2.8.3 Screening Remedial Action Alternatives

Consistent with USEPA guidance, remedial action alternatives may be screened prior to the detailed and comparative evaluation of remedial action alternatives based on effectiveness, implementability, and cost. As a practical matter, remedial action alternatives may be screened concurrent with the development step. Ultimately, alternatives that fail to meet the following requirements should not be carried forward into the detailed evaluation of remedial action alternatives:

1. Achieve RAOs in a reasonable time period.
2. Comply with applicable laws and regulations.
3. Have proportionate costs relative to overall effectiveness in comparison to other alternatives.
4. Have acceptable short term effects.

2.9 Step 6 - Evaluation of Remedial Action Alternatives

Evaluation of the remedial alternatives developed should consider a range of evaluation criteria consistent with the regulatory framework that the site is being remediated under. Under CERCLA, the detailed evaluation of remedial action alternatives includes both an evaluation of each alternative and a comparative evaluation in which each alternative is compared against one another. Specific criteria for the evaluation of remedial action alternatives are presented below. Because the criteria presented here are commonly used outside of CERCLA as well and are generally standard practice in the industry, these criteria mirror the nine NCP evaluation criteria. Since this guidance applies to remedial actions taken under different state regulatory authorities as well as RCRA and CERCLA, the criteria are designed to apply to multiple programs.

Although specific evaluation criteria are included in this guidance document, the actual detailed evaluation of remedial action alternatives should be based on the requirements of the regulatory authority under which the site is being evaluated and remediated. This guidance does not change or supersede existing laws, regulations, policies, or guidance documents. This guidance also includes several additional areas of consideration that are important for evaluating remedial action alternatives at contaminated sediment sites, including criteria related to green and sustainable remediation, habitat and resource restoration, watershed considerations, and future land and waterway use.

Evaluation criteria for remedial action alternatives are typically organized into the following major categories:

- ability to meet project objectives (such as RAOs)
- effectiveness (such as long-term reliability and short-term impacts)
- technical feasibility (which addresses the question: Can this be done?)
- administrative feasibility (which addresses the question: Can required approvals be obtained?)
- cost and schedule
- ability to meet stakeholder objectives

Sediment sites are different from upland sites in several ways that affect the evaluation of alternatives. These unique factors include the following:

- In most cases, a sediment site cannot be considered in isolation from the surrounding environment since the groundwater, overlying surface water, and aquatic life are integral to the physical, chemical, and biological systems.

- Fish tissue goals may not be achievable due to background conditions and watershed sources.
- The persons responsible for the remedial action and those performing the actions often have limited control over past, current, or future use of public waterways.
- Remedial actions are most often done under water, so it is not possible to work as precisely as when working on land.
- Many objectives relate to the long-term performance of ecosystems, which are affected by factors other than chemical concentrations in sediment (for instance, climate change).
- Remediation goals for sediment contaminants, developed to protect human health and the environment, may have the ancillary benefit of improving habitat and restoring ecosystem function.
- Risks to aquatic organisms are typically a result of exposure to contaminants within or delivered through the biologically active zone (BAZ), such as by groundwater upwelling.
- Risks to human health are typically a result of ingestion of fish or shellfish that have been exposed to contaminants in the BAZ, and to a lesser degree from direct contact exposure.

The feasibility study should include an assessment of individual alternatives against each of the evaluation criteria and a comparative analysis that focuses on the relative performance of each alternative against those criteria. The purpose of this comparative analysis is to identify the advantages and disadvantages of each alternative relative to one another so that the key tradeoffs that the decision-maker must balance can be identified. The comparative analysis should include a narrative discussion describing the strengths and weaknesses of the alternatives relative to one another with respect to each criterion. The differences between alternatives can be presented either qualitatively or quantitatively and should identify substantive differences.

In many regulatory programs, including the NCP, the regulations do not provide any direction on relative weights assigned to evaluation criteria. While every attempt should be made to evaluate individual alternatives objectively and with equal weight, different stakeholder perspectives may give greater weight to one evaluation criteria over another. For example, some stakeholders may give greater weight to cost, while others may give greater weight to long-term effectiveness.

A more structured approach to the comparative analysis of remedial action alternatives may be used to quantitatively weight and score remedial action alternatives during the feasibility study process. These tools can range from simple spreadsheets to more sophisticated software packages, which can be tailored to meet the specific needs of the feasibility study process. Tools that may be used to facilitate the evaluation of remedial action alternatives include comparative risk analysis (CRA) and multi-criteria decision analysis (MCDA). Under CRA, a two dimensional matrix is developed for the purpose of evaluating criteria or quantitatively aggregating quantitative scores for each criteria and comparing aggregate scores. MCDA provides a more sophisticated approach for evaluating and ranking the various decision criteria. MCDA allows the decision-maker to assign different weights to the evaluation criteria and to understand the sensitivity of the evaluation to changes in each of the decision criteria. The benefits of multi-parameter analysis tool use is that the decision factors in the remedy selection, the weighting of each factor being considered, and the score applied to each remedial alternative are clearly defined and readily available for review.

If a full quantitative multi-parameter tool is not deemed appropriate or necessary for comparing alternatives, qualitative forms of comparison may be used for sediment sites to provide similar results. Examples of these comparisons are presented in the series of figures below. Figure 2-2 presents a knee of the curve analysis to measure cost against reductions in fish tissue concentration. Figure 2-3 presents the time to achieve protection for each alternative as a bar graph. Figure 2-4 presents progress towards RAOs for each alternative on a five-year time interval basis. Figure 2-5 presents weighted overall benefit against cost for each alternative.

Figure 2-2 (modified from Bridges 2012) provides a hypothetical depiction of the costs of alternatives plotted against the benefit of risk reduction as measured by predicted declines in fish tissue levels following remedial activities. For example, a cost of $20 million to reduce fish tissue concentrations to 0.25 mg/kg compared to an additional cost of $20 million to reduce the fish tissue concentration to 0.1 mg/kg. Although this figure depicts predicted declines in fish tissue concentrations, this type of presentation can be used to conduct a "knee of the curve" analysis for any measure of risk reduction (such as sediment concentrations) to identify the point at which the increased cost of a remedial alternative only results in an incremental reduction in risk.

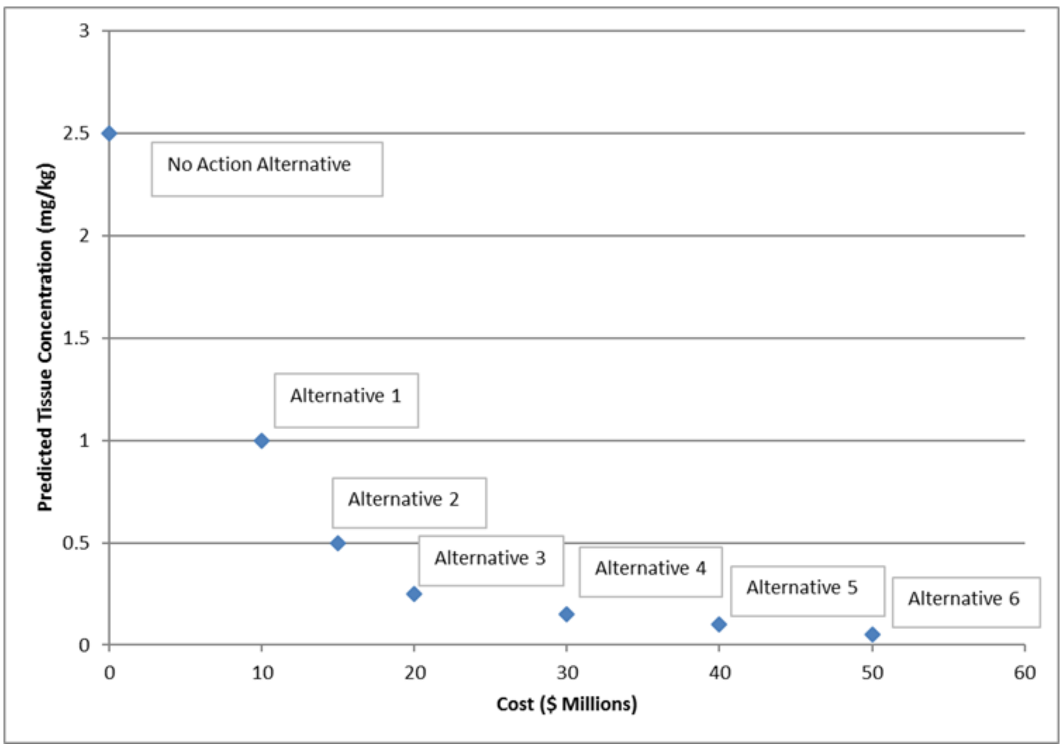


Figure 2-2. Risk reduction (represented by fish tissue concentration) versus cost of various alternatives.

Source: Modified from Bridges, Nadeau, and McCulloch 2012a, Figure 1.

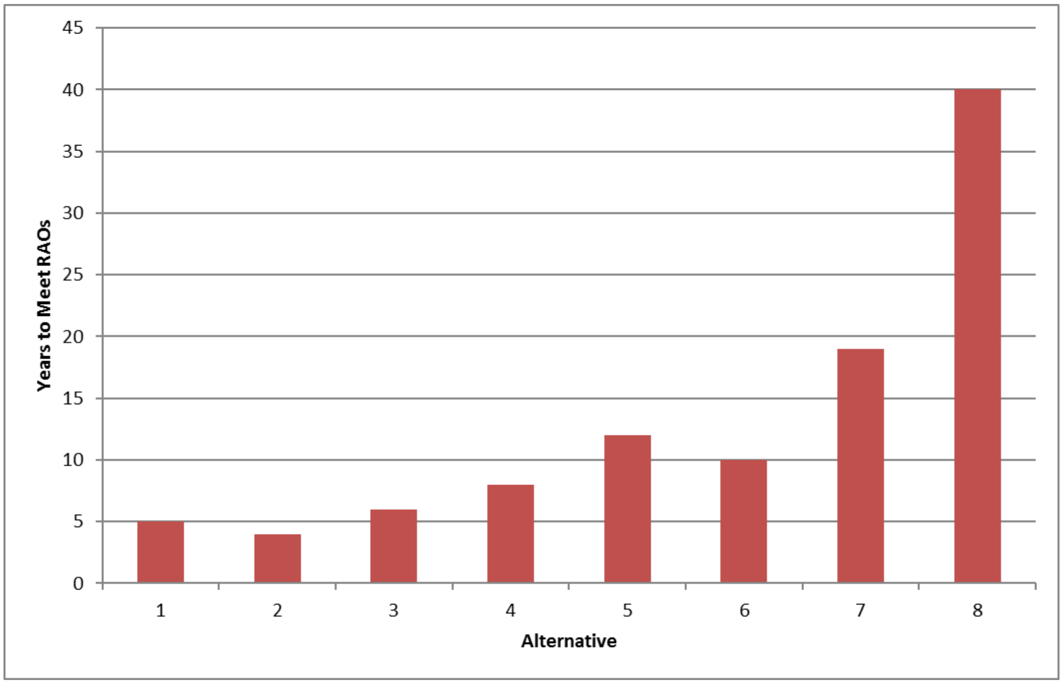


Figure 2-3. Time to achieve cleanup objectives for RAOs for all alternatives.

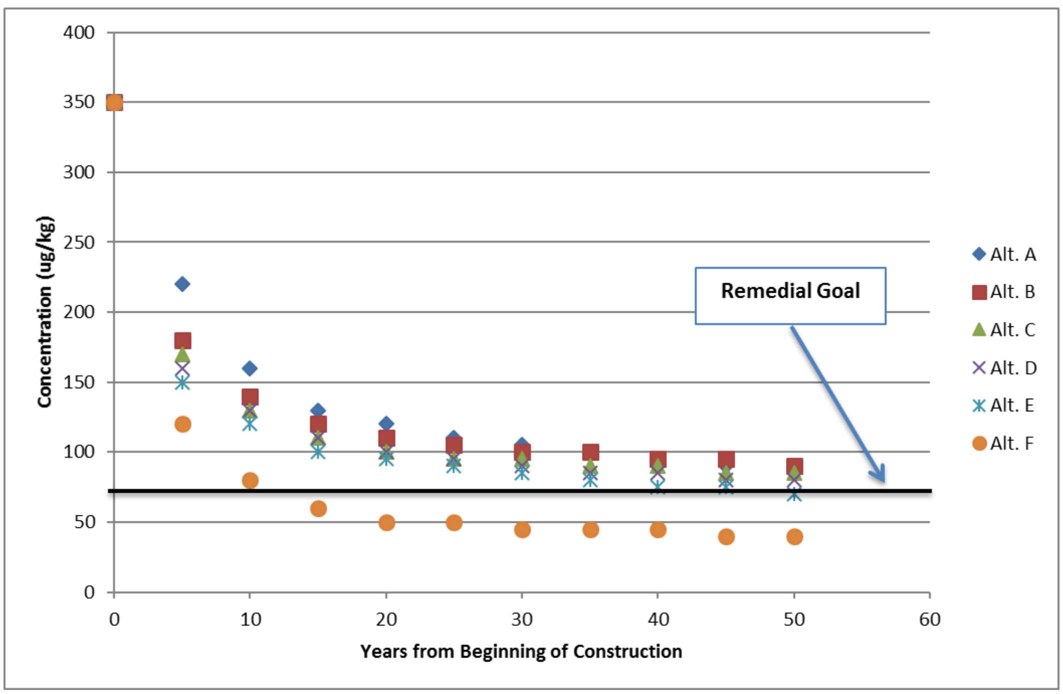


Figure 2-4. Estimated final concentration of COPC after implementation to demonstrate long-term effectiveness of each alternative.

Another tool for comparing alternatives is a cost-benefit analysis, in which the evaluation criteria are synthesized into one overall net benefit score for each alternative. Figure 2-5 presents an example stacked bar chart that summarizes the benefits for each alternative in comparison to the overall cost of the remedy. The evaluation should consider both positive effects, such as long-term effectiveness as measured through risk reduction, and negative effects, such as the adverse effects associated with implementation. Information presented in the graph can be evaluated to determine at what point the additional benefit achieved per additional dollar spent becomes very low. For example, as shown on Figure 2-5, as the alternatives become more aggressive (towards the right hand side of the graph), the weighted benefit becomes fairly constant while the cost increases dramatically. The weighting assigned to each benefit is a multi-criteria decision analysis that is subjective and site-specific. Different values and weightings may be assigned differently from site-to-site depending on the environmental, economic, and social burdens and benefits being applied to a particular site.

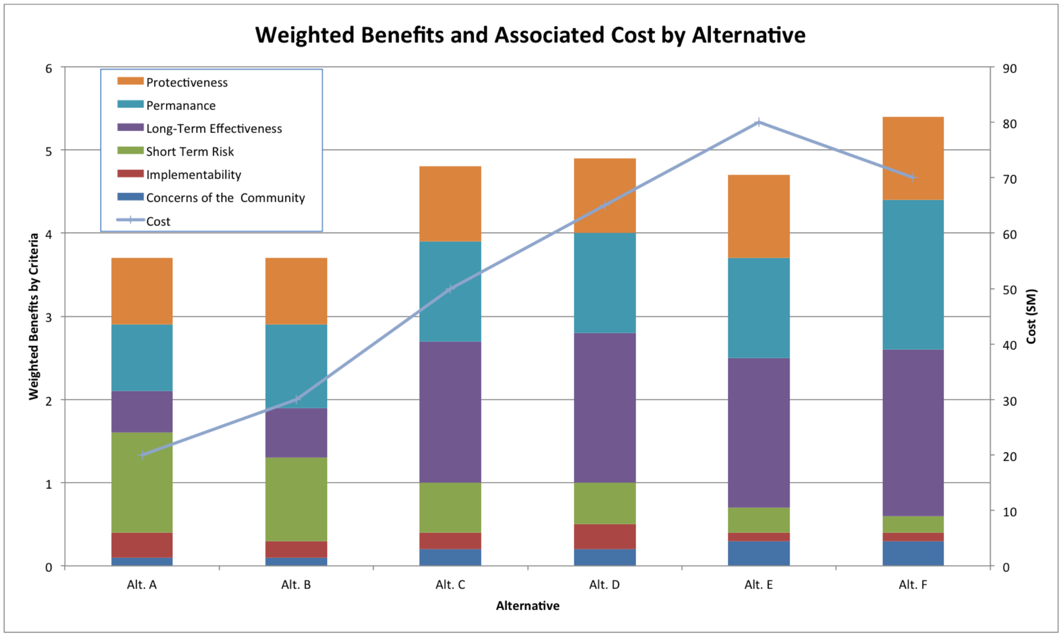


Figure 2-5. Weighted benefits and associated cost by alternative.

The comparative evaluation of alternatives requires a balancing of costs against the overall effectiveness of a remedy. Overall effectiveness can also be a narrative evaluation of the extent of risk reduction and the time to achieve this reduction and meet the established cleanup goals for a project. A *knee of the curve* analysis (or cost-benefit analysis) can help identify the relationship between cost and overall risk reduction. The tools presented in this section are only examples and may or may not be applicable to every contaminated sediment site. The exact nature of the evaluation tools will be a function of the regulatory requirements that the sediment site is being remediation under and the weight given the various criteria by the interested parties to the project.

2.9.1 Overall Protection of Human Health and the Environment

Protectiveness may be achieved through a combination of active remediation, MNR/EMNR, and institutional controls. When evaluating sediment remedial alternatives, be aware that project objectives related to protecting human health and the environment may not be met at the end of remedial action implementation without the incorporation of institutional controls. In addition, for many sites, MNR over some time frame will be required to meet the protectiveness criteria.

Site-specific cleanup goals for sediments are typically established based on either human health or ecological risk. In many cases, such as for persistent bioaccumulative and toxic contaminants, risk-based cleanup levels are well below background and not technologically achievable. In this instance, site cleanup levels should be established based on background levels consistent with current USEPA policy or state regulatory requirements.

Exposure of aquatic organisms to sediment typically takes place within the BAZ. As a result, in the cases where surface sediment does not exceed cleanup goals but surface sediment is contaminated, dredging to remove contamination deep within the sediment may not reduce risk to protective levels for human health or the environment. In cases where groundwater advection is transporting contamination into the BAZ, however, or where future events (such as dredging activities or episodic erosion events) have the potential to re-expose buried sediments, efforts to address subsurface sediment contamination may be required to meet RAOs.

Mass removed does not necessarily correspond to net risk reduction or long-term effectiveness. Analysis of surface contamination during the evaluation of remedial alternatives must consider the potential for exposure to subsurface contaminants to occur in the future. At sites where cleaner sediment has already buried sediment with higher contaminant concentrations, dredging for mass removal may result in higher risk as the sediment with higher concentrations is exposed or resuspended into the water column (thus increasing the post-dredge residual surface concentrations).

2.9.2 Compliance with Laws, Regulations, Permits, and Appropriate Requirements

In general, site remedies must comply with applicable laws, regulations, and permits. Under CERLCA, compliance with ARARs is required. In some instances certain administrative requirements may be waived as long as the substantive intent of the requirement is met. It is beyond the scope of this guidance document to describe the process whereby compliance with applicable laws, regulation and permits must be demonstrated or the process by which certain requirements may be waived.

Under CERCLA, ARARs include requirements that are applicable to the circumstances of the site as well as requirements that, while not applicable, are considered relevant and appropriate to the circumstances of the sites. Local ordinances, advisories, or guidance that do not meet the definition of ARARs are typically referred to as "to be considered" requirements. Three types of ARARs are described under CERCLA:

- chemical-specific requirements (concentration standards)
- location-specific requirements (restriction of remediation activities at sensitive or hazard-prone locations)
- action-specific requirements (typically treatment, removal, transportation, and disposal of hazardous waste)

With few exceptions (such as Washington State Chapter 173-204 WAC Sediment Management Standards), no numeric standards exist for sediments. Although most states have narrative water quality requirements that require sediment to be free from chemical constituents that pose a risk to human health or the environment, narrative requirements should be incorporated into the RAOs for the site based on the results of the baseline human health and ecological risk assessments. Screening values such as probable effects concentrations (PECs) are not ARARs and do not need to be achieved to meet threshold requirements though they may be used as screening criteria or other measures of risk. Location- and action-specific requirements may include the need to obtain water quality certifications, in-water work schedule windows, Clean Water Act and endangered species mitigation, and land disposal requirements.

2.9.3 Long-Term Effectiveness and Permanence

The evaluation of long-term effectiveness and permanence focuses on the risk remaining at the site following the implementation of the remedy and the effectiveness of any controls required to manage the risk posed by contaminated sediments left in place (for example, below sediment caps or backfill placed to manage residuals). The magnitude of residual risk is typically measured based on the level of contamination left in place, the volume or concentration of material managed through engineering and institutional controls, and the degree to which the remaining contamination remains hazardous based on the contaminant volume, toxicity, mobility, and propensity to bioaccumulate. The adequacy and reliability of engineering and institutional controls determines how the remedy limits future exposure and the potential need to replace technical components of the alternative (such as cap refreshment). For contaminated sediment sites, factors related to the potential for future exposure, such as groundwater migration and erosion potential, must be considered.

Active remediation (dredging, capping, or in situ treatment) causes short-term effects to the benthic environment and overlying surface water quality. These short-term effects must be balanced against long-term effectiveness. Water quality controls (such as a silt curtain, portable dam, or sheet pile containment), operational best management practices for dredging and placing materials, and in-water work schedule windows can minimize, but not eliminate, short term effects.

Containment remedies are effective and reliable in the long-term for sites where the sediment is stable and source control has been achieved, which is common even in rivers. At many sites, relatively high concentrations of persistent chemicals are present in the immediate vicinity of where source materials were discharged as long as 75 to 100 years ago. This situation occurs frequently in rivers and harbors adjacent to former coal gasification plants. These facilities may have been closed for decades, yet NAPL and PAH impacted sediments remain near the facilities. For these sites (if they are stable), in situ containment may be a reliable remedy.

For sites where dredging or isolation capping is used as the primary technology to meet cleanup goals based on specific chemical concentrations, short-term effects to the aquatic ecosystem are expected. RAOs are not likely be achieved until after recolonization of the site by benthic organisms and subsequent re-establishment of the ecosystem. In many situations the best remedy is a combination of technologies that uses dredging, capping, and in situ treatment (as a stand-alone technology or as a component of a reactive cap) to remediate source areas with the highest chemical concentrations and MNR/EMNR to reach final objectives. Capping and dredging are often used in combination where removal of contaminated sediments is required to allow cap placement or where thin layer placement of sand is required to prevent exposure to dredging generated residuals.

2.9.4 Reduction in Toxicity, Mobility, and Volume Through Treatment

This evaluation criterion addresses the evaluation of remedial actions that use treatment technologies that permanently and significantly reduce toxicity, mobility, or volume of the hazardous substances as their principal element. Areas of high concentration (hotspots) should be assessed to determine whether they represent principal threat material under CERCLA or some other regulatory threshold that may result in a preference for early treatment or removal. Under CERCLA, a preference exists for treatment to address the principal threats at a site through destruction of toxic contaminants, reduction of the total mass of toxic contaminants, irreversible reduction in contaminant mobility, or reduction of the total volume of contaminated media. At contaminated sediment sites, the evaluation of reduction in toxicity, volume, and mobility is primarily focused on the use of reactive materials to reduce contaminant mobility and bioavailability through direct placement (in situ treatment) or as part of a cap design (amended capping).

2.9.5 Short-Term Effectiveness

This evaluation criterion addresses effects due to the construction and implementation of an alternative until objectives are met. Under this criterion, alternatives should be evaluated with respect to their effects on human health and the environment during implementation of the remedial action. Monitoring releases during dredging or cap placement, and the duration of remedy implementation, are key factors in evaluating short-term effectiveness.

For sites where dredging or isolation capping is used as the primary technology to meet cleanup levels based on specific chemical concentrations, short-term effects to the aquatic ecosystem occur (from resuspended sediments or residuals). RAOs will not likely be achieved until after recolonization of the site by benthic organisms and subsequent re-establishment of the ecosystem. As with long-term effectiveness, in many situations the best remedy may be a combination of technologies that uses dredging or capping to remediate areas with the highest chemical concentrations and natural recovery to reach final RAOs.

2.9.6 Feasibility

Feasibility includes both technical and administrative components. A technical feasibility evaluation includes a site-specific determination of how active remediation would be implemented at the site, considering site-specific conditions and lessons learned from similar sites. Site access is an important consideration for sediment remedial actions, especially at former industrial sites where the responsible parties no longer own the property and residential development has occurred along the shoreline. Lack of access to areas to process materials can have a significant effect on the feasibility of alternatives. Additional factors to consider include availability of equipment and materials and disposal sites that may be needed. Note the distinct difference between technical feasibility evaluations of remedial alternatives and a technical impracticability (TI) waiver at a Superfund site. A TI waiver cannot be justified on cost alone; the remedy must be technically demonstrated to be non-implementable (USEPA 1993).

An administrative feasibility evaluation includes items such as permit approvals, right-of-entry (if the water body is not on land owned by the responsible parties), regulatory agency approvals, and resource agency approvals. Many sediment sites are on land owned and managed by federal, state, tribal, or local governments and therefore are subject to various laws, regulations, and policies that govern activities in the waterways. This situation can lead to restrictions on what can be done, how work is done, and when it can be performed. Additionally sites may include sensitive or critical habitat for threatened and endangered species or sites of historical importance. Both of these conditions will require administrative approval from those agencies directly responsible for implementation of the respective federal and state laws. If sediment removal is required at a historic site, then recovery of the historic artifact may be required in advance of remedy implementation, which will affect both schedule and costs.

2.9.7 Cost

Assessment of cost, as a remedial action alternative evaluation criteria, is often a complex undertaking. Not only is the financial cost of the remedy important, but costs must also be estimated for the loss of the use of the resources during remedy implementation. Many factors beyond the cost of the technology being evaluated must be considered, such as material costs, transportation costs, storage costs, and monitoring costs. As an example, costs for dredging and capping depend on a number of factors:

- volume and area to be dredged or area to be capped
- depth of water; costs are higher for shallow water depths (less than 5 ft) or deep water (greater than 50 ft)
- type of water body (river, harbor, lake, pond, mudflat, or other)
- site access and upland work areas at the site
- transport of contaminated sediments and capping material
- availability and location of sediment disposal sites
- sediment dewatering, water treatment and discharge permitting
- remedy effectiveness monitoring
- sediment physical properties
- sediment chemical concentrations
- sediment classification (hazardous or nonhazardous)

- quantity and type of debris in sediment
- schedule

When assessing cost for any alternative, consider seasonal restrictions and limits on work hours that may increase the time it takes to complete remedy construction. For example, in many regions of the country, in-water work is not allowed at certain times of the year in order to protect sensitive aquatic resources.

Site-specific variables may have a substantial impact on schedule and final cost of the alternative. Care should be taken to account for every possible major cost factor when making a final remedy selection.

2.9.8 Stakeholder and Tribal Acceptance

Solicit input from state and tribal stakeholders during the alternative evaluation process and incorporate their input into the decision making process. Stakeholder interests or concerns should be considered during the development of RAOs, as appropriate. Consideration of stakeholder interests and concerns should begin during the RI/FS process to develop early consensus regarding project goals. Consideration of stakeholder interests can become more critical during the development of remedial action alternatives (Section 8.0). Most sediment sites involve many more nonregulatory, or community, stakeholdersthan upland sites. These stakeholders may include:

- recreation and commercial users of the water bodies
- organizations representing recreational or commercial uses
- landowners along the shoreline
- owners of lands under the water (may be governments)
- local government representatives
- environmental protection organizations
- port management districts or organizations

Community acceptance will vary based on the nature of the community, the potential impacts of the cleanup, and the extent to which the contaminated sediment resource is valued. Failure to engage community stakeholders in the process could result in unacceptable delays in the remedial process.

2.9.9 Green and Sustainable Remediation

Green and sustainable remediation (GSR) is becoming increasingly important in site remediation. Aspects of GSR are being introduced into decision making throughout the site remediation process, from investigation through design and monitoring. ITRC's *Green and Sustainable Remediation: A Practical Framework* (ITRC 2011b) presents a GSR planning and implementation framework, provides definitions of the GSR components, references GSR tools, and offers a discussion of GSR integration into various stages of the site remediation process. The key GSR concepts relevant to sediment remediation include the following:

Protectiveness

As global pressures to save energy and limit greenhouse gas (GHG) emissions increase the definition of protection may, from some perspectives, include a balance of local benefits of sediment cleanup with global environmental costs.

Compliance with ARARs

ARARs incorporate sustainability-related considerations, such as sensitive habitats and wetlands. This criterion could be expanded to include social settings such as schools, environmental justice zones, or densely populated areas representing the social component of sustainability. Ultimately local or national laws may need to regulate activities related to factors such as GHG emissions or fuel usage to be included in the category of ARARs. In such cases, technologies with a large environmental footprint may not be selected as a final remedy.

Effectiveness

Effectiveness is a broad concept that can incorporate GSR. The ability to achieve and maintain cleanup levels in light of recontamination (due to background or lack of source control) is a form of sustainability that should be considered. However, additional aspects of effectiveness can include: whether the remedy achieves the desired social benefits to the community and whether the remedy effectively promotes ecological restoration. Almost any target attribute can be considered under this criterion.

Reduction in Mobility, Toxicity, and Volume

Reduction of mobility, toxicity, and volume can promote sustainability by encouraging remedies other than removal. Although many new in situ treatment technologies for sediment are still emerging or evolving, these technologies hold promise as remedies with reduced intrusiveness. However, ex situ treatment technologies that are energy intensive or require large-scale removals may not meet sustainability objectives.

Short-Term Effectiveness

Short-term effectiveness is a result not only of the remedy functioning quickly, but also of the incidental adverse effects caused by remedy implementation. Social impacts of GSR (such as noise, traffic, loss of use of the resource, air impacts) are considered here. Large-scale sediment removal projects are often associated with negative short-term social effects. However, these affected communities may also benefit socially and economically from resources that are restored in a shorter time frame. Communities may also benefit from other economic considerations such as use of local labor and supplies as well as ancillary use of food and lodging (especially for long-duration projects).

Feasibility

Feasibility encompasses both the technical and administrative feasibility. As with ARARs, a growing body of legislation may eventually restrict activities that do not meet GSR criteria.

Cost

The economic impact includes the actual cost of the remedy as well as economic impact to the community. The "cost" is not simply an accounting of dollars spent: the true cost must account for the direct and indirect impacts to the environment, community, and site workers. Sediment dredging, dredged material processing, water treatment, and disposal consume large quantities of energy and other resources, which results in direct negative effects on the environment. For sites where off-site disposal of dredged material is performed, each truck driven to the landfill burns fuel, releasing air pollutants adding to the carbon footprint, and increases traffic congestion. Although cost has always been a balancing consideration in remedy selection, as a key component of the GSR triad, cost must consider the broader metrics. These costs to society can be balanced with the long-term costs of not remediating the resource in terms of lost economic value, recreational hours (economic), human health cost due to exposure (multiple generations when it is in the regional food chain), quality of life, productivity issues for workers, compromised habitat and fisheries (tribal hunting and fishing rights as well as commercial fisheries), bioaccumulation in aquatic wildlife with wide aquatic range, and endangered species. It is therefore essential that resources be focused on remediation that provides the most benefit. Often times, once a community has had contamination removed from its waterfront development area, it begins to prosper.

2.9.10 Habitat and Resource Restoration

In many instances, full recovery of an ecosystem at contaminated sediment sites requires habitat and resource restoration in conjunction with site remediation. CERCLA allows for natural resource damage assessments (NRDA) and the recovery of damages by natural resource trustees for the loss of resources associated with the release of hazardous substances. Coordination with the natural resource trustee agencies is recommended to facilitate the incorporation of NRDA restoration activities into sediment site remedies where applicable.

In addition to NRDA, mitigation may be required under the Clean Water Act (CWA) or the Endangered Species Act (ESA) for the unavoidable loss of resources (such as shallow water habitat) or impacts to endangered species. The cost of CWA or ESA mitigation activities should be incorporated into the evaluation of sediment remedies. Furthermore, these costs can be minimized through incorporation of habitat improvements into the site remedy. For example, the incorporation of a habitat layer into a sediment cap may be considered adequate to eliminate the need for additional CWA or ESA mitigation.

2.9.11 Watershed Considerations

Watershed-wide contamination from nonpoint runoff or atmospheric deposition may limit the degree of risk reduction that sediment remediation can achieve. In addition, releases from other sites or urban stormwater may recontaminate a sediment site under remediation or limit the effectiveness of MNR and EMNR. As a result, all sediment sites should include the development of a CSM that identifies watershed inputs and characterizes background conditions. Consider the degree and time frame of source control efforts when evaluating sediment remedies. For example, are upstream sediment sites expected to be remediated in the near future? Are requirements in place for the future control of combined sewer overflow discharges? Are atmospheric sources derived from the watershed at levels that will support attainment of PRGs or is attenuation of these sources also necessary to eventually achieve the targets?

2.9.12 Future Land and Waterway Use Considerations

Consider future land and waterway use in the development and evaluation of remedial action alternatives as presented in Table 2-3. All site remedies must be compatible with reasonably anticipated future land and waterway use considerations. For example, the remedy should anticipate whether the site is expected to be a future recreational area, habitat area, residential development area, or industrial area with berthing facilities, because future use significantly influences the feasibility of sediment remedies. Future conditions are often uncertain, however, so consider the degree of this uncertainty when evaluating remedial action alternatives. Additionally, consider watershed goals though coordination with stakeholders throughout the remedy selection process.

3.0 MONITORED NATURAL RECOVERY AND ENHANCED MONITORED NATURAL RECOVERY

Monitored natural recovery (MNR) is defined by the National Research Council (2000) as a remediation practice that relies on natural processes to protect the environment and receptors from unacceptable exposures to contaminants. This remedial approach depends on natural processes to decrease chemical contaminants in sediment to acceptable levels within a reasonable time frame. Enhanced MNR (EMNR) applies material or amendments to enhance these natural recovery processes (such as the addition of a thin-layer cap or a carbon amendment). Parallel natural or enhanced processes, taken together with observed and predicted reductions of contaminant concentrations in fish tissue, sediments, and water, provide multiple lines of evidence to support the selection of MNR/EMNR (Magar et al. 2009). The success of MNR/EMNR also depends on adequate control of contributing sources of contamination (see Section 2.3) so that the recovery processes can be effective. MNR is not viable as a stand-alone remedial technology if it does not achieve the RAOs.

3.1 MNR and EMNR Background Information

MNR can be used alone or in combination with active remediation technologies to meet RAOs. EMNR can use several technologies including, but not limited to, thin-layer capping and introduction of reactive amendments such as activated carbon (AC). Thin-layer caps (typically up to one foot) are often applied as part of an EMNR approach. These caps enhance ongoing natural recovery processes, while minimizing effects on the aquatic environment. Thin-layer caps are not intended to completely isolate the affected sediment, as in a conventional isolation capping remedy (see Chapter 5). Instead, the thin-layer cap provides a top layer of cleaner sediment, which reduces surface chemical concentrations so that benthic organisms can colonize the sediment. This layer also accelerates the process of physical isolation, which continues over time by natural sediment deposition.

Evaluation of MNR/EMNR during the FS step is highlighted in the *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (USEPA 2005a). Using MNR as a remedy at a contaminated sediment site requires a thorough understanding of the sources, exposure pathways, and receptors in the CSM. Site managers must be able to predict, with some degree of certainty, that contaminant concentrations will decline or be effectively addressed within a specific time frame. Numerical modeling of sediment contaminant levels and biota tissue levels are thus essential tools for defining timely goals and tracking the effectiveness of MNR (Suter et al. 2000).

3.2 Approaches to and Objectives for MNR/EMNR

With MNR, contaminated sediments are left in place and monitored for ongoing physical, chemical, and biological processes that transform, immobilize, isolate, or remove contaminants until they no longer pose a risk to receptors. MNR relies on a natural decrease in sediment contamination and a reduction in bioavailability or toxicity of chemicals following accretion of clean suspended sediment. Natural processes that contribute to MNR may include sediment burial, sediment erosion or dispersion, and contaminant sequestration or degradation (for example, precipitation, adsorption, or transformation). These natural processes, discussed in detail below, can reduce exposure to receptors (and thus reduce risk) and contribute to the recovery of the aquatic habitat and the ecological resources that it supports.

3.2.1 Physical Processes (Burial and Dispersion)

Physical processes relevant to contaminated sediments include depositional or erosional processes, groundwater upwelling, and sediment transport events (such as scour, propeller wash, or tidal effects). These processes can help or hinder a sediment remediation project and must be considered prior to selection of MNR. The primary process responsible for successful MNR is the deposition of cleaner sediment that buries and isolates the contamination. Contaminants in surface sediments, especially in the BAZ (the upper bioturbation layer) often pose the greatest risk of chemical exposure to benthic receptors and to humans through ingestion of contaminated fish or shellfish or by direct contact. Reducing surface sediment concentrations or chemical bioavailability is thus the primary goal of sediment remediation processes.

A good example of physical burial by natural deposition and MNR is presented in the Koppers Barge Canal case study. Located on the Ashley River in Charleston, SC, the Koppers Barge canal has a shallow slope and the estuary is turbid. With each tidal cycle, suspended sediment is left behind. Mixing of residual COCs occurs through bioturbation by fiddler crabs. Yearly monitoring showed significant decreases in site-related COCs. This example shows that, with successful source control, the deposition of cleaner sediments results in lower surface sediment contaminant concentrations over time. Additionally, the Lower Fox River case study and Twelve Mile Creek/Lake Hartwell case study present two examples in which dispersion and physical isolation were the primary physical processes for the natural recovery of large aquatic ecosystems contaminated with low levels of PCBs. Many sites often include some form of MNR in the remedy when either low zones of contamination are present or the sites are located in depositional areas. Other case studies documenting physical isolation through burial are presented in the ESTCP MNR technical guidance (ESTCP 2009).

MNR can be affected by periodic or episodic erosion events, which can disperse surface sediments across a larger area. Erosion can be a problem when COC concentrations are high and control of scour or erosion is desirable. For low-level contaminated sediments, however, dispersion can result in dilution of COCs and ultimately achieve the site-specific cleanup objectives.

3.2.2 Chemical Processes (Sequestration and Transformation)

Two categories of chemical processes can effectively reduce contaminant bioavailability and toxicity: sequestration and transformation. Attenuation of contaminants via sequestration (sorption, for example) is promoted through adsorption, complexation, and in situ precipitation (or co-precipitation). Transformation generally occurs through natural microbial processes that will either change a parent chemical into a less toxic metabolite (for example, Cr(VI) → Cr(III)) or degrade a constituent through metabolic reactions (phenol → CO_2 + H_2O). Transformation into a more toxic metabolite (such as methylated mercury or selenium) can also occur.

3.2.2.1 Sequestration (Sorption and Precipitation)

Sorption is the partitioning of a dissolved contaminant from the aqueous phase onto the surface of a solid phase (adsorption) or diffusion of the contaminant into the sediment matrix (absorption). Partitioning of a contaminant from the mobile aqueous phase to the stationary sediment matrix is often quantified using the ratio of the concentration of the contaminant adsorbed to the sediment to the concentration of the contaminant dissolved in the surrounding water at equilibrium (the partition coefficient, K_d). The higher the K_d, the greater the percentage of contaminant mass partitioned to the solid. Use of K_d values is common, but these values are often measured in the laboratory and are more variable when measured in the field. For example, within a given site at any one time, multiple K_d values may be measured for a contaminant because of spatial variability in mineralogy and chemistry. More complex treatments of sorption require more characterization data. Ultimately, site managers must balance the level of complexity and data needs with the level of acceptable uncertainty. For organic compounds, K_d is normalized by dividing it by the sediment fraction of organic carbon to yield the K_{oc}. The normalized value is a better indicator of how strongly an organic contaminant binds to the solid phase of a sediment.

Solids precipitation may lead to contaminant sequestration by three principal routes:

- precipitation of a pure-phase mineral when sufficient metals and ligands are present
- co-precipitation or complexation, in which the formation of a solid phase captures a metal contaminant within the mineral matrix
- sorption of a metal contaminant onto surfaces of a freshly precipitated solid-phase sorbent material

Precipitation occurs when the aqueous phase becomes saturated with either a metal or a metal and ligand which causes the formation of an insoluble phase (for example, the reaction of lead with phosphate to precipitate insoluble pyromorphite, or the reaction of mercury with sulfide to precipitate insoluble cinnabar; see ITRC CS-1, Section 2.1.2). In the process of precipitation, the metal contaminant is incorporated within the mineral matrix of the dominant solid phase and essentially substitutes for the major ion within the mineral matrix of the newly precipitated solid phase. In the case of co-precipitates, where the contaminant metal in question is a minor constituent of the mineral precipitation, the solubility of the metal contaminant in question depends on the solubility and dissolution of the dominant mineral matrix. Commonly occurring solid phases principally responsible for attenuation or sequestration of metals in sedimentary environments include, but are not limited to, hydroxide, carbonate, phosphate, and sulfide minerals. An example of this process is the co-precipitation of arsenic by iron hydroxide complexes as landfill leachate transitions from a reducing to an oxidizing environment.

3.2.2.2 Transformation (Degradation)

Chemical reactions such as photolysis, hydrolysis, and oxidation/reduction are responsible for contaminant transformations in sediments (Schwarzenbach, Gschwend, and Imboden 2003). Microbes mediate many of these reactions. For example, MNR was the selected remedy for “Area A” in the Hackensack River, a 34-acre estuarine parcel which had received chromium ore processing residue for over a hundred years. The reducing nature of the sediments converted Cr(VI) to Cr(III), which transformed this potentially toxic element to a form that is not bioavailable to aquatic organisms.

In some cases, abiotic degradation can occur. Some organic contaminants, such as nitroaromatic compounds, can be rapidly transformed in sediments (such as abiotic reduction by ferrous iron). Other organic contaminants (PAHs, PCBs, and PCDDs/PCDFs) are resistant to degradation and therefore are extremely stable in the environment. These recalcitrant compounds, however, may still undergo chemical reactions such as electrophilic substitution, oxidation, and reduction. Chemical transformation alone may occur over time periods of years or decades; however, most of these chemical transformation reactions can be catalyzed by metabolic activity of microorganisms in sediments. Contaminant transformation should thus be considered in the context of biological mediation and the biological aspects fundamental to the reaction chemistry (benthic habitat and nutrient status).

3.2.2.3 Transformation (Radioactive Decay)

Radioactive decay, the only process by which elemental contaminants are subject to transformation, is applicable to specific isotopes of certain contaminants. Radionuclides are subject to the same environmental attenuation processes related to sorption, precipitation, and redox reactions as described above; however, they also exhibit radioactive decay characteristics resulting in their transformation. Radionuclide decay follows first order kinetics, which means that the rate of the decay is proportional to the number of nuclei present. Consequently, each radionuclide has a characteristic half-life. Five half-lives are required for the loss of greater than 95% of any given radionuclide, and ten half-lives for 99.9%. In contaminated sediment systems, the radiological half-life must be considered in the context of the time needed to achieve remedial objectives. For certain elements with short half-lives (seconds to years), the toxicity of the radiological decay products must be considered. For those elements with long half-lives (centuries to millennia), radioactive decay is not a viable MNR process.

3.2.3 Biological Processes

Biological characteristics of sediments often govern site-specific MNR attenuation processes. The microbial community and the nutrients that sustain its metabolic processes are often key to the site-specific attenuation process (for example, mineralization of organic compounds or sulfate reducing bacteria (SRB) catalyzing metal sulfide precipitation). The indigenous benthic community, where sediment dwelling organisms mix oxygen-containing surface sediments with anoxic deeper sediments, also strongly affects bacterial population dynamics (for example, by sediment ingestion and production of fecal pellets).

Microbial process can directly or indirectly change the bioavailability and the toxicity of a contaminant (ITRC 2011a). Direct processes include degradation of an organic contaminant to innocuous products or changes to valence states of metals affecting speciation, solubility, and bioavailability (see Hackensack River case study). Indirect processes include changes in bulk pH and oxidation-reduction potential. ORP affects geochemical conditions and thus the disposition of redox sensitive metals. Metabolic processes, such as iron or sulfate reduction, can indirectly affect contaminant attenuation by producing or depleting geochemical reactants that may govern contaminant fate. An example of a metabolic process is the production of sulfide by SRBs. Sulfide can combine with divalent metals to form insoluble metal sulfides. Areas of microbial iron reduction can produce excess ferrous iron, which can facilitate the reductive transformation of organochlorines or nitroaromatics to less toxic compounds.

Phytoremediation is another approach for MNR of sediments, primarily in riparian zones and areas of shallow water. Plants may absorb contaminants directly or accelerate contaminant transformation as a result of their metabolic processes. Water hyacinth, which is a robust species (particularly in tropical wetlands), has been explored for the cleanup of shallow contaminated sediments. Furthermore, selective planting of indigenous species, adapted to the local climate, can enhance the MNR processes already under way at a site. Increasing aquatic vegetation through plantings decreases water velocity, thus encouraging deposition of suspended sediment and increasing the organic carbon content of local sediments. In some cases, it may be necessary to harvest the plants to remove contaminants from the system.

3.2.4 Enhanced Monitored Natural Recovery

EMNR consists of an engineered amendment, such as placement of a thin-layer cap or injection of a carbon based sorbent into the surface sediments. The objective of EMNR is to accelerate the process of physical isolation, which is continued over time by natural sediment deposition. EMNR also enhances ongoing natural recovery processes (such as burial and sorption) and minimizes more invasive effects to the aquatic environment (for example, aquatic habitat that would be lost with dredge and fill). These sediment amendments do not completely isolate chemically impacted sediment as in a conventional capping operation (Chapter 5). Instead, the sediment amendment speeds the development of a surface layer of cleaner sediment, which results in the reduction in surface chemical concentrations and facilitates the re-establishment of a healthy benthic community. Implementation of EMNR must be based on a demonstration that situ recovery can achieve RAOs in a reasonable time. For example, the EMNR solution implemented at the Ketchikan Pulp Company site (Merritt et al. 2009) achieved both an effective isolation of thick, organic-enriched sediments (containing elevated sulfide and ammonia) and a benthic substrate more conducive to the recolonization of a the benthic macroinvertebrate community. Like MNR, EMNR is validated over time through performance monitoring (ESTCP 2009).

3.3 Design Considerations

If appropriate for the site conditions, MNR/EMNR offers a relatively low-cost, low-risk option that provides a high level of effectiveness and permanence. Selection of the optimal remedy for a specific site, however, requires consideration of multiple factors, some unrelated to the environment (such as budgetary constraints and public opinion). Typically, MNR/EMNR is used in concert with active remedial technologies that can quickly eliminate exposure, such as dredging and capping.

3.3.1 Design Advantages

Unlike active remediation technologies (dredging and capping), MNR is noninvasive and does not disrupt or destroy biologically active zones. MNR is beneficial in wetland environments where rare or threatened endangered species exist, or where existing habitats would not recover from a disturbance for a long time. In these cases, the value of sensitive habitats outweighs the benefits of removing or capping the contamination. MNR, however, requires monitoring of the natural recovery process of an ecosystem over time.

MNR also avoids the contaminant resuspension that commonly occurs during capping or dredging. These more invasive technologies may create conditions that hinder rather than help efforts to attain RAOs. Dredging, for instance, can cause resuspension of sediments, release of bound contaminants, exposure of residual concentrations associated with the dredge cut, and additional ecological and human health risks generated by greater contaminant levels following re-exposure (NRC 2007b). Postdredging monitoring data collected at a number of sites have also demonstrated temporary spikes in water column and fish tissue levels following construction activity. If higher COC concentrations are buried below the biologically active zone, dredging can re-mobilize the contaminant back into the ecosystem, re-exposing the biological community to COCs. As a result, risks to the biological community are increased and site cleanup may be prolonged. Contaminant mass reduction may thus not be an optimal solution if it results in an increase in net risk.

Capping also has potentially negative effects. For instance, unconsolidated native sediments may not have sufficient load bearing capacity to support the capping material. The placement of capping material also results in destruction of habitat. Furthermore, contaminants contained in the pore water of unconsolidated sediment can be released to the cap and surface water (USEPA 2005a). Additional concerns arise from the availability of a suitable capping material, minimum required water depth, water body uses, ebullition, and groundwater advection conditions adjacent to the site.

Secondary advantages of MNR/EMNR addressed elsewhere in this chapter include the following:

- Low implementation effort results in relatively low costs (costs are primarily associated with demonstrating the effectiveness of MNR).
- Multiple risk reduction processes can occur concurrently; these processes are primarily physical, but can also include chemical or biological processes such as the dechlorination of PCBs.
- Mixing (by bioturbation) of contaminated sediment with overlying clean sediment can reduce contaminant concentrations.
- MNR/EMNR is applicable to locations where dredging or capping are infeasible (such as

large areas of relatively low contamination).

- MNR is less disruptive to human activities than other remediation methods.

3.3.2 Design Limitations

MNR is not a viable remedy when the physical, chemical, and biological processes are not expected to achieve RAOs within a reasonable time. MNR may not be viable when sediment deposition rates are inadequate for timely burial, when sediment erosion (such as ice scour) is likely, or where advection may be a substantial source contribution. Areas with stable sediments but inadequate deposition rates in terms of achieving RAOs in an acceptable time frame, however, may be good candidates for EMNR.

A major drawback for MNR is that contaminated sediment is left in place and could be reintroduced into the environment. This shortcoming must be considered in light of potential degradation rates. Leaving the contaminated sediment in place also results in a public perception that MNR is a "do-nothing" approach. At sites where this misconception exists, public education is critical.

Another limitation of MNR, which affects all remedial alternatives to some degree, is the uncertainty associated with the data, the site CSM, and model predictions. Uncertainty can result from unexpected disturbance to the sediment, changes in sedimentation and resuspension rates, bioavailability, and abiotic or biotic transformation rates. Confidence in MNR as a remedial solution is gained by developing multiple lines of evidence to minimize uncertainty by defining declining trends in contaminant concentrations in fish tissue and sediment through consistent monitoring of the site over time. Providing routine updates to the stakeholders on the outcome of the remedy also builds confidence in this remedial approach.

MNR also requires long-term monitoring to verify that the RAOs are met. Because of the difficulty of meeting some RAOs (for instance, the removal of a fish advisory), some monitoring programs can be overly burdensome. Eagle Harbor, for example, has been monitored for over 18 years.

Natural groundwater or surface water discharges, if related to the site, can make MNR infeasible. For example, significant quantities of dissolved and particulate phase contaminants may pass into ponds or lakes through surface runoff. The long-term transport of low levels of bioaccumulative substances must therefore be regarded as a confounding variable when making MNR decisions in any watershed.

Secondary limitations of MNR (some of which also apply to more invasive remedial technologies) that are addressed elsewhere in this chapter include the following:

- Interim risks are managed with institutional controls, such as fish advisories to limit consumption.
- Uncertainties associated with model-based predictions translate to uncertainties about the time required to achieve RAOs.

- Contamination is left in place, where it can potentially be transported by diffusion and erosion associated with extreme weather.
- Additional costs that may be incurred include institutional controls, such as fish advisories to limit consumption, as well as public education. Long-term monitoring costs may be significant at some sites.
- Demonstration of future degradation can be challenging; for instance, prediction of PCB dechlorination rates is difficult.
- Concentration reductions in sediment and fish tissue take time. Identifying actual trends can sometimes take years due to natural variability.
- The long-term effectiveness of MNR requires long-term monitoring strategies.

3.3.3 Additional Considerations for Implementation

Before implementing an MNR or EMNR design, several factors should be taken into account to avoid unnecessary delays and subsequent cost, including:

- institutional controls and future use restrictions
- time required to reach cleanup objectives
- stakeholder and community acceptance

3.3.3.1 Institutional Controls

Most remedial alternatives include institutional controls until long-term monitoring indicates risk reduction has been achieved and the RAOs have been met. Remedies that include MNR frequently require institutional controls, such as fish consumption advisories, to limit human exposure during the recovery period. Institutional controls often require public education programs and postings of warning signs.

3.3.3.2 Time Frame to Reach Cleanup Objectives

The time frame for natural recovery is often longer than that predicted for dredging or capping. Time frames for various alternatives may overlap when uncertainties are taken into account. In addition, realistic estimates of the longer design and implementation time for active remedies should be factored into the comparison. For example, when a single RAO for unlimited fish consumption exists, the time required for MNR, capping, and dredging alternatives may not differ greatly because the active remedial measures can initially result in a spike in fish tissue levels. These possible outcomes should be communicated to the public and other stakeholders before a remedial option is finalized.

3.3.3.3 Public and Community Stakeholder Acceptance

Public and community stakeholder acceptance is one of the two modifying criteria under the NCP; the other is state acceptance (USEPA 1998). Remedies such as MNR may have poor public acceptance at the outset. If disruption due to off-site transport and disposal is not an issue, communities typically prefer that contaminated material be dredged and removed from the area. Stakeholders should be made aware, however, that in general no remedial technology can remove all contaminants from a sediment site.

Remedies that leave site contaminants in place have some risk of continuing exposure or re-exposure of buried contaminants. When MNR is based primarily on natural burial, some risk exists for buried contaminants to be re-exposed or dispersed if the sediment bed is significantly disturbed. A disturbance can result from unexpectedly strong natural forces (ice scour or flooding), through human activities (boating, dredging, or construction), or by groundwater advection. Public acceptance often hinges on a clear CSM, a logical analysis of remedial alternatives, and a robust long-term monitoring program. Informing the public about the tradeoff between risks and benefits associated with contaminants that are left in place, capped, or removed, is key in creating support for the MNR decision. Multiple lines of evidence are necessary to establish the expected permanence of an MNR remedy and to achieve remedy acceptance.

3.3.4 An Example CSM in Support of MNR – Sediment Contamination by Groundwater-Surface Water Interaction

The CSM should call out data needs and lines of evidence necessary to evaluate the various complex physical and biogeochemical factors required to evaluate MNR/EMNR as viable remedial alternatives. At a minimum, the CSM should address the following: source(s), nature and extent of contamination, sediment transport pathways and mechanisms, sediment deposition rate; exposure pathways associated with chemical contamination, and the potential for in situ degradation (see following example). The RI CSM identifies which major processes must be evaluated and investigated using a sediment transport evaluation or sediment erosion and deposition assessment for the site.

Discharge of contaminated groundwater to surface water is gaining more attention as a mechanism of sediment contamination, particularly for organic chemicals. A former dye manufacturing plant that used chlorinated solvents offers one example of this mechanism.

Sediment Contamination by Groundwater-Surface Water Interaction at a Dye Manufacturing Facility

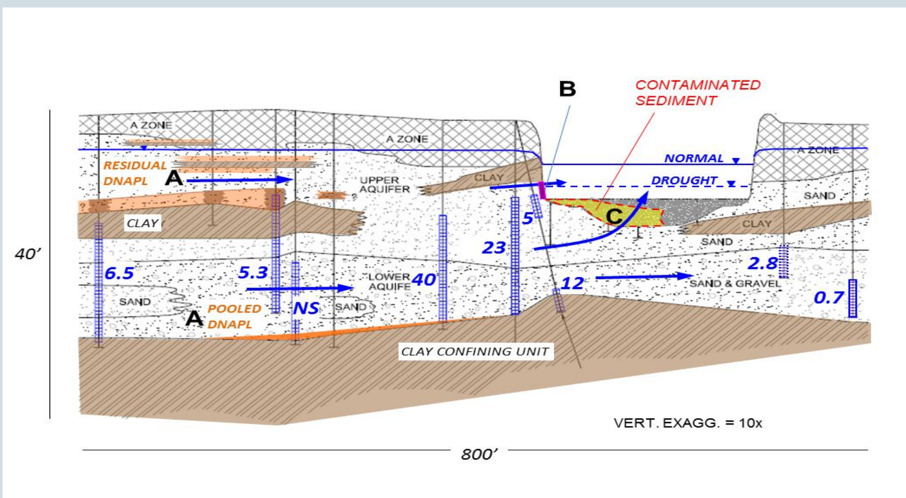
During a drought, the water level in a freshwater canal was low, and purple water was observed seeping from the canal sidewall into the water. An initial round of sediment samples revealed that chlorobenzene concentrations in the sediment were above ecological screening criteria. An extensive round of groundwater, surface water, sediment, and soil sampling was then performed to identify the source of the seep and the extent of affected sediment. Water levels in the canal and in neighboring wells were also monitored to establish the hydraulic connection between groundwater and surface water. The principal elements of the resulting CSM are described and illustrated below:

1. A groundwater plume originates from a dense nonaqueous phase liquid (DNAPL) zone in the nearby manufacturing area.

2. The seep observed during the drought is the groundwater plume discharging from the upper portions of the shallow aquifer.

3. The sediment is contaminated because volatile organic compounds (VOCs) in groundwater sorb to the organic-rich sediment as the plume migrates upward through the sediment.

Comparison of measured groundwater concentrations beneath the sediment to sediment pore-water concentrations supports this model. Groundwater chlorobenzene concentrations (µg/L) are shown below in blue.



Since the discharging plume was the cause of the sediment contamination, sheet piling was installed to prevent further discharge. Compound specific isotope analysis indicated that degradation of the VOCs was occurring in groundwater. Anaerobic degradation in the sediment was also expected because of the anaerobic environment. Thus, source control (removal of the source by stopping groundwater discharge) and biodegradation provided the means to initiate an MNR remedy. Samples have been collected since the sheet piling was installed and are being evaluated to assess the effectiveness of this coupled source control and biodegradation remedy.

After the CSM is developed, study questions and problem statements can guide the plan in addressing specific data needs. Sufficient data should be gathered to answer the following questions for each identified sediment zone:

- What is the nature and extent (horizontal and vertical) of sediment contamination at the site?
- What is the likelihood of erosion and deposition and where are these processes likely to occur within the site?
- At what rate will exposed contaminated surface sediment be buried?
- Could buried contaminated sediment become exposed?
- Although the whole site may be net depositional, are there areas within the site that are net erosional?
- Can source zones become erosional, or subject to periodic erosion such that contaminated media can be transported elsewhere within the site?
- What are the natural and anthropogenic processes that are likely to affect sediment transport at the site?
- Could on-site sediment transport lead to recontamination of the site?
- Will chemical and biological transformation of the COCs contribute to attaining cleanup goals?
- What is the expected time required to meet cleanup goals?
- Are there documented reductions in surface sediment contaminant concentrations over time?

The preliminary CSM and the preceding questions form the basis for developing Data Quality Objectives that are used to plan field investigations and environmental studies (for example, to support sediment transport evaluations and sediment erosion and deposition assessments) needed to evaluate whether MNR and EMNR are viable alternatives. The following sections describe the data needs and lines of evidence necessary to evaluate whether MNR/EMNR should be selected as a remedy at sediment sites.

3.4 Data Needs for MNR and EMNR

An evaluation of natural recovery and sediment transport processes must be completed prior to fully developing either MNR or EMNR as viable remedial alternatives. Data needed to evaluate the natural recovery processes at sediment sites fall into four general categories (see Table 2-1): physical site characteristics, sediment characteristics, contaminant characteristics, and land and waterway use characteristics. Data needs are most often addressed during RI field activities and by performing a sediment transport evaluation or sediment erosion and deposition assessment, as described in the *User's Guide for Assessing Sediment Transport at Navy Facilities* (Blake et al. 2007). NAVFAC's *Technical Guidance for Monitored Natural Recovery at Contaminated Sediment Sites* (ESTCP 2009) provides a framework for MNR and EMNR data needs specifically for contaminated sediment programs. If MNR or EMNR are expected to be used in the sediment site remedy, then the planning stage of the sediment transport evaluation/sediment erosion and deposition assessment (STE/SEDA), conducted prior to alternative evaluation and remedy selection, should address investigating potential mechanisms of the fate of COCs, such as transport, burial, and degradation.

3.4.1 Physical Site Characteristics

Data regarding the physical and hydrodynamic processes occurring at a sediment site are critical for evaluating MNR/EMNR remedies. Measures of the forces (discharge, waves, currents, tides) that drive the major sediment transport processes (erosion, water column transport, deposition) are necessary to effectively evaluate MNR/EMNR remedies (Blake et al. 2007).

3.4.1.1 Sediment Stability

Sediment bed stability can be assessed by using calculated estimates or literature values based on sediment properties. Surficial critical shear stress and resuspension potential can be obtained for cohesive sediments (such as by using a shaker/annular flume) from core samples. Sediment erosion profiles with depth can be characterized for cohesive sediments using Sedflume or other similar methods. Another line of evidence that demonstrates sediment stability is the vertical profile of contamination in the sediment, which reflects the history of contaminant releases and source control efforts in highly stable sediments. *If natural burial processes indicative of stable sediments have occurred at the site following cessation or reduction of contaminant releases, then contaminant concentrations should be lower at the surface. Additionally, the contaminant concentration profile should be trending from a peak concentration at depth toward the background concentrations at the surface.*

3.4.1.2 Sediment Deposition Rate

Sediment deposition rate can be established by evaluating historical bathymetric differences in conjunction with reviewing dredging records, coring followed by radioisotope analysis, sediment traps, and pin/pole surveys. *For MNR/EMNR, the annual sedimentation rates should be greater than erosion or resuspension rates (annual net deposition). For MNR/EMNR technologies that rely on burial, the annual sedimentation rates should be greater than erosion or resuspension rates (positive net deposition). Sites with annual net deposition much greater than annual erosion and resuspension and with annual net deposition rates greater than roughly 0.5 cm/yr are prime candidates for MNR/EMNR.*

Although sediment deposition rate is a critical data need for those MNR/EMNR remedies that rely on burial as a primary recovery mechanism, deposition rates outside of this stated range may also be acceptable depending upon the specifics of the CSM (including vertical extent of contamination, sediment stability, and erosion potential). These metrics, as well as others discussed in Chapter 3, should also be evaluated to determine MNR/EMNR viability. An example calculation illustrating the interdependency of these metrics is provided below.

Target Risk Reduction Example

Where risk reduction depends primarily on burial from deposition, the bioactive zone can be represented as a completely mixed zone if the burial is the result of annual events (not infrequent large episodic events). The decay in bioactive zone concentration can be represented by the decline in the concentration in a completely stirred reactor by steady flushing.

The achievable target risk reduction by burial can be estimated as follows:

$$Co/C = 1 / e\text{-}Qt/T$$

where:

Q = deposition rate, cm/yr (net deposition rate plus erosion/resuspension rate; resuspension rates typically range from 0.1 to 1 cm/yr in slow moving water bodies, increasing with velocity and decreasing with water depth)

T = bioturbation depth, cm

t = maximum allowable recovery time, years

Co = existing bioavailable concentration in the bioactive zone, ppm

C = target bioavailable concentration in the bioactive zone, ppm

For example, if the bioturbation depth were 10 cm and the deposition rate were 1.1 cm/yr (net deposition rate of 0.6 cm/yr and resuspension rate of 0.5 cm/yr), the predicted concentration reduction factor in 30 years would be

$$Co/C = 1/e\text{-}(1.1 \text{ cm/yr} * 30 \text{ yr} / 10 \text{ cm}) = 27$$

If the bioturbation depth were 5 cm and the deposition rate were 0.4 cm/yr (net deposition rate of 0.2 cm/yr and resuspension rate of 0.2 cm/yr), the predicted concentration reduction factor in 25 years would be

$$Co/C = 1/e\text{-}(0.4 \text{ cm/yr} * 25 \text{ yr} / 5 \text{ cm}) = 7.4$$

If the bioturbation depth were 15 cm and the deposition rate were 1.8 cm/yr (net deposition rate of 1.0 cm/yr and resuspension rate of 0.8 cm/yr), the predicted concentration reduction factor in 20 years would be

$$Co/C = 1/e\text{-}(1.8 \text{ cm/yr} * 20 \text{ yr} / 15 \text{ cm}) = 11$$

EMNR can be evaluated using the same approach, except that Co should be adjusted to reflect the initial dilution or partial burial of the bioactive zone by the material applied.

Note: Target risk reduction equation is based on a sediment mass balance without degradation presented in Boyer et al. 1994, Chapra and Reckhow 1983, and Jacobs, Barrick, and Ginn 1988.

3.4.1.3 Erosion Potential

Sediment erosion properties must be defined to determine the potential for removal of protective sediments during extreme events. Non-cohesive sediment behavior can generally be predicted from grain size and bulk density information. Cohesive sediment behavior may require the use of other tools to evaluate erodibility. STEs address hydrologic and hydraulic processes that influence the erodibility of sediments and the probability of episodic hydrodynamic events, which may result in the loss of the protective sediment layer and increase the potential exposure to COCs in underlying sediments. *The erosion potential of the sediments should be evaluated with consideration of site-specific recovery mechanisms, estimated recovery time, and the expected effect of episodic hydrodynamic events.* If the critical shear stress of the sediments below the bioactive zone is lower than the shear stress that may be produced under episodic high energy events, then further evaluation is required to confirm the stability of the protective sediment layer throughout the recovery period. Note that a high suspended sediment load also may indicate a high erosion potential in some areas.

3.4.1.4 Water Depth and Bathymetry

Water depth can be assessed using maps, NOAA bathymetric charts, aerial photographs, and other available regional and site-specific data (current and historical). Detailed bathymetric surveys using single or multi-beam mapping systems can also be conducted. A basic level of bathymetric, topographic, and historical information is needed to characterize a site because physical boundaries often define the relevant zone of influence. A bathymetric/shoreline change analysis can yield information on long-term depositional or erosional characteristics of the system (sediment sources and sinks) and help quantify rates of change. *Water depth is not a critical consideration for MNR. EMNR, however, may have depth limitations similar to in situ treatment (see in situ treatment TAG, Section 4.4.1.9).* The literature indicates that accurate delivery and placement methods are improving, thus expanding the application of EMNR for a wide range of aquatic environments.

3.4.1.5 In-water and Shoreline Infrastructure

Information describing current or historical in-water and shoreline infrastructure can be obtained from local agencies and or developed from site specific data collected while visually inspecting the site. In-water and shoreline infrastructure is usually not an issue when considering MNR. For EMNR, however, structures may limit accessibility or require specialized equipment to be used for amendment application. Delivery and placement methods are improving, making EMNR a more viable remedial option even where access is limited.

3.4.1.6 Presence of Hard Bottom and Debris

The presence of a hard bottom or debris in sediments is typically not a constraint for MNR that target contaminants in surficial sediments. EMNR on the other hand, requires placement of the treatment amendment on the sediment surface, in which case the presence of debris must be considered.

3.4.1.7 Hydrodynamics

Hydrodynamic information can be obtained from regional or site-specific flow data. Site-specific measurements are necessary, however, to characterize the hydrodynamics of the area within, and immediately upstream, of the site. These measurements include the following:

- current measurements, using acoustic Doppler velocimeter (ADV), ADCP, pulse coherent acoustic Doppler profiler (PC-ADP), S4, or velocimeters
- tide and wave measurements, using pressure sensors, ADCP wave array, and S4
- salinity and temperature profiles in estuaries

Seasonal hydrodynamics generally control the erosion potential of the site sediments (Section 3.4.1.3). The dominant seasonal hydrodynamic forces should be identified and quantified because these forces drive sediment transport. When these data are combined with suspended sediment measurements, directions and quantities of sediment transport can be determined. Additionally, analysis of water column transport properties is necessary to determine sediment flux on site and off site and to determine settling properties of sediments.

3.4.1.8 Slope and Slope Stability

The weight of material placed for EMNR (thin-layer sand covers) imposes a new load on the underlying sediment. When the sediment surface is sloped, this weight produces a force that pushes the cover and underlying sediment downslope. The force pushing downslope is resisted by the shear strength of the underlying sediment. In slope stability calculations, the ratio of the force available to resist sliding to the force pushing downslope is called the *factor of safety*. The minimum factor of safety for permanent slopes under static loads is generally 1.5, based on guidance documents such as *Design Manual 7.2, Soil Mechanics* (NAVFAC 1986). *For EMNR slope stability, the factor of safety under static loads should be greater than 1.5.* The factor of safety decreases as the sediment shear strength decreases, as the thickness of the cover material increases, or as the slope angle increases. Slope stability calculations are recommended when the slope is greater than 5% or when the sediment shear strength is less than 1 kPa (20 psf). Thin-layer cap placement may require special design and placement methods when the slope is greater than 15%. As discussed in Section 5.4.1.6, the sediment must have sufficient strength to support the weight of EMNR cover material without lateral displacement (mud waves) of the sediment under the cover.

3.4.1.9 Groundwater-Surface Water Interaction

Seasonal groundwater flow data, groundwater and chemical data, and pore-water data are needed to understand the potential groundwater and surface water interaction at a site. Data can be collected using piezometers, groundwater modeling, infrared surveys, salinity gradient surveys, flux chamber measurements, and seepage meter measurements. A variety of passive and active pore-water samplers are available also (ITRC 2011a, Appendix C).

Groundwater must be characterized as part of the CSM, both as a potential source of chemical contamination and as a physical transport mechanism (advection). Effects of groundwater advection on dispersion of sediment contaminants can be identified using pore-water chemistry, which characterizes surface sediment dissolved chemical concentrations. Groundwater springs and heavy discharge areas may also cause sediment to be unstable and contribute to long-term dispersion of particulate bound contaminants, as well as dispersion of dissolved-phase contaminants in certain site-specific environments. Sediment stability (Section 3.4.1.1) and contaminant contributions from groundwater discharge must also be considered when evaluating MNR/EMNR.

Long-term contaminant migration rates by groundwater advection upwards through the newly deposited sediment should be substantially less than the long term burial rate. Contaminant flux rates are generally much lower than the groundwater flux rate due to the adsorptive capacity of the sediment. Long-term monitoring and verification of assumptions are recommended to assure site conditions are consistent with the input parameters of the flux rate calculation.

The contaminant flux rate is calculated by dividing the pore-water velocity (Darcy flux divided by the porosity of the sediment deposition) by the retardation coefficient, R. The retardation coefficient is calculated as follows:

$$R = 1 + (\rho_b K_d / n)$$

where:
R = retardation coefficient
ρ_b = dry bulk density, kg/L
K_d = partition coefficient, L/kg = $f_{oc} K_{oc}$
f_{oc} = fraction organic carbon
K_{oc} = organic carbon/water partition coefficient, L/kg
n = porosity

As an example, a burial rate of 0.5 cm/yr for a sediment with 3% TOC, a specific gravity of 2.6 and a porosity of 0.7 (ρ_b = 0.78 kg/L) would require a groundwater flux less than 585 cm/yr (1.6 cm/dy) for a contaminant having a K_{oc} of 100,000 L/kg. (K_d = 3,000 L/kg for the deposition; R = 3344).

3.4.2 Sediment Characteristics

In addition to understanding the physical, biological, and geochemical characteristics present at a contaminated sediment site, a site-specific evaluation of sediment characteristics is necessary prior to implementing MNR/EMNR. The data needs for specific sediment characteristics required to evaluate the feasibility of MNR/EMNR are summarized in the following sections.

3.4.2.1 Geotechnical Properties

Geotechnical parameters strongly affect the physical disposition characteristics of the sediment bed and therefore affect the fate and transport of contaminants over space and time.

Initial estimation of bulk density, shear strength, and cohesiveness can be measured based on preliminary sediment characterization. Surficial critical shear stress and resuspension potential for cohesive sediments, using shaker/annular flume and sediment erosion profiles with depth, can be estimated using Sedflume. These measurements are useful in determining the potential for sediment erosion and potential depths of erosion during extreme events. Non-cohesive sediment behavior can generally be predicted from grain size and density information.

3.4.2.2 Grain Size

Grain size data can normally be obtained from typical RI or equivalent information. Sieve analysis should be obtained for sediments greater than 63 μm and laser diffraction methods for high resolution less than 63 μm. Generally for MNR/EMNR, a high percentage of fines is indicative of a low energy (potential depositional) environment. Sediment bed property data can be used to infer the sediment transport characteristics based on distributions and sorting of sediment grain sizes and densities.

3.4.2.3 Resuspension, Release, and Residuals

Resuspension or release of COCs is not a concern for MNR or EMNR, as long as the physical site characteristics and geotechnical parameters are well understood.

3.4.2.4 Sediment Consolidation (Pore-water Expression)

Sediment consolidation is evaluated using percent solids data, which should be available from sediment analytical data in the RI or equivalent study. Centrifugation of a sediment sample is typically performed to determine the fraction that consists of pore water. Additional data collection, such as sediment consolidation tests, can provide engineering properties necessary to evaluate the potential application of EMNR. This data may be needed because settlement of the sediments can cause contaminant flux into newly deposited material or material used for EMNR.

Sediment and pore-water geochemical data (including TOC, DOC, and POC) can normally be obtained from an RI (or equivalent) or supplemental sediment and pore-water sampling. Geochemical constituents related to contaminant binding (bioavailability) or decay (transformation/degradation) should be targeted. The effectiveness of MNR/EMNR typically increases with increasing natural sorption capacity (for example, with the presence of organic carbon, including highly sorptive black carbon) of sediment and suspended sediment in the waterway. Sorption of contaminants by organic carbon reduces bioavailability, which reduces exposure even if total contaminant bulk sediment concentrations are not reduced (ITRC 2011a).

Sediment data should also be used to determine the concentration, source, and spatial distribution of geochemical constituents (such as sulfide or manganese) responsible for contaminant attenuation and sequestration. Measurement of acid-volatile sulfide/simultaneously extracted metals (AVS/SEM) helps to assess the bioavailability of divalent metals.

3.4.2.5 Benthic Community Structure and Bioturbation

Literature data on benthic community characteristics (such as species inventory, habitat evaluation, burrowing depths, and bioturbation rates) should be reviewed. When evaluating benthic habitat, sediment profile imaging can identify the presence and types of burrowing organisms, indicate the depth of redox zones, and measure the bioturbation depth. Metrics such as abundance and diversity of the benthic community can also be measured following taxonomic evaluation of organisms preserved from conventional sediment grabs (ESTCP 2009). Sediment sites with a relatively deep BAZ (greater than 10 cm) may not be remediated as quickly as those with a shallower zone (less than 5 cm), but MNR can be used at sites with deeper BAZ if given enough recovery time. The acceptable length of the recovery period is a site-specific decision. EMNR is most effective when the emplaced layer thickness exceeds the BAZ depth.

Recolonization of the benthic community typically follows the placement of the enhancement layer. The bioturbation depth influences the rate of change in surface sediment chemical concentrations. Benthic mixing can affect the rate of physical isolation of the contaminated sediment below. Benthic bioturbation depths also indicate how to define surface sediments (sediments to which organisms may be exposed). Without site-specific data, 10–15 cm depth as an average may be assumed. Benthic community structure may be used to evaluate the recovery of the community.

3.4.3 Contaminant Characteristics

The types, properties, concentrations, and distribution of contaminants present at a site and their potential to be transported or transformed must be understood when considering MNR/EMNR. Table 2-2 presents some of the data that help to better define the factors that affect the disposition of COCs for MNR/EMNR. A key objective of any sediment remediation is the reduction in bioavailability, toxicity, and volume of COCs, which in turn directly reduces site risk. For MNR/EMNR, these reductions are best accomplished through physical isolation (natural burial) and degradation (such as reduced half-life). Natural sedimentation provides further reductions in chemical mobility and leads to reduced contaminant concentrations in surface sediment through natural dilution and burial.

Although most sediment guidance calls for an assessment of bioavailability, this process is often inadequately addressed or even ignored. Bioavailability can be a key factor in the decision to use MNR (for example, low bioavailability is a favorable line-of-evidence) and EMNR (for example, the use of sorptive media can markedly reduce bioavailability of bioaccumulative compounds) (ITRC 2011a). At a minimum, TOC should be measured in all samples to estimate partitioning behavior of COCs. AVS/SEM data are also valuable, particularly in estuaries or marine environs, for predicting bioavailability of and risk from divalent metals (Hammerschmidt and Burton 2010).

3.4.3.1 Horizontal and Vertical Distribution

Sediment chemistry data typically collected from the RI (such as high-resolution horizontal and vertical sediment contaminant distribution data) can be used to evaluate the contaminant extent. If contaminant sources and loading history are known, then sediment transport patterns can be inferred from the horizontal and vertical contaminant distribution. Some sediment constituents (aluminum, iron, and others) can act as a tracer for the transport of contaminants away from the site, to normalize site-specific contamination (metal ratios), and to identify potential off-site sources contributing to sediment contamination. *MNR remedies are most effective when contaminant concentration increases with depth, indicating that a natural burial process occurs at the site. Lower surface concentrations, over time, translate to a lower degree of risk.*

3.4.3.2 Contaminant Type

A detailed evaluation of the nature and extent of contaminants and their potential to migrate or be transformed is essential to understanding risks posed by a site over time and whether natural recovery mechanisms that rely on transformation are viable. A literature review of typical fate and transport behavior of chemicals (such as metals, chlorinated organics, pesticides, and UXO) in sediment should be conducted. This review and testing should include speciation and valence state data, partition coefficients, typical half-life in sediments, and factors that control migration such as organic carbon, sulfides, sediment geochemical data, and pore-water data. USEPA's online EpiSuite program can assist in predicting many fate and transport parameters, including biodegradation probability, octanol-water partition coefficient (K_{ow}), organic carbon partition coefficient (K_{oc}), bioconcentration factor (BCF), and bioaccumulation factor (BAF).

3.4.3.3 Contaminant Concentration

A review of historical site information and a literature review of chemical data and reference or background data is helpful in understanding the distribution of contaminants present at the site. Key exposure routes and receptors for these contaminants should have already been identified during the development of the site CSM and risk assessment. Reducing risks from these contaminants often depends on changes in site-specific factors and conditions that can be used to make a decision for MNR/EMNR. These factors include sediment deposition rates, degradation rates of COCs, the recovery of the benthic community, and the acceptable time period in which to achieve the remediation goals. These site-specific factors can be used to determine the concentrations of COCs that are amenable to MNR and the concentrations of COCs that are amenable to EMNR (as illustrated in the *Target Risk Reduction Example* in Section 3.4.1.2).

For sediments that have characteristics (such as sediment stability) suitable for MNR or EMNR, the risk reduction is primarily achieved by reducing the bioavailable contaminant concentration in the BAZ, where significant sediment mixing occurs by bioturbation. This zone is typically the top 6 inches (15 cm) of the sediment profile in freshwater systems and the top 12 inches (30 cm) of sediment in estuarine and marine systems. The target risk reduction factor can be expressed as the ratio of the existing bioavailable contaminant concentration in the BAZ to the remediation goal (RG). This factor may be estimated by the ratio of the existing dissolved contaminant concentration in the BAZ to the target dissolved contaminant concentration.

For example, at a site with a deposition rate of about 1.1 cm/yr, a BAZ thickness of 10 cm, and the desire to achieve the remediation goals within 30 years, concentrations of COCs 27 times or less than the remediation goals are amenable to MNR and concentrations of COCs 100 times or less than the remediation goals are amenable to EMNR (see the *Target Risk Reduction Example* in Section 3.4.1.2 for applicable equations and examples).

3.4.3.4 Exposure Pathways

MNR and EMNR can control exposure pathways to the aquatic food web that involve direct or indirect exposure to the available chemicals in the sediments. These pathways may include a direct exposure to biota, bioaccumulation into benthic invertebrates with subsequent transfer to higher trophic levels, and contaminant flux to the overlying water column. Natural burial processes can eliminate direct exposure to contaminants in the sediments through physical isolation of the contaminated sediments from the overlying water column biota. Chemical transformation and sequestration (immobilization) can reduce or eliminate the bioavailability of contaminants to the bioactive zone and subsequent food web.

The CSM should clearly determine whether natural sediment chemical and biological processes and net deposition are capable of controlling the exposure pathways to the aquatic environment. The immediate threat from direct exposure of the aquatic environment to the contaminants in the sediment can be reduced by the addition of sediments to the natural sediment surface. This enhancement should be designed to accommodate any erosional effect, thus preventing a re-occurrence of direct exposure to contaminants. Amendments may be added to the sediment surface to enhance the degradation and immobilization capabilities of the surface sediment.

3.4.3.5 Source Material

Identifying the sources of contamination are especially critical for MNR/EMNR because continued loading from in-water sources may prevent MNR/EMNR from achieving RAOs. Examples of source material include NAPL, sand blast grit, slag, and areas of highly contaminated sediment that are ongoing sources of contamination through sediment transport, advective groundwater transport, or other transport mechanisms (Section 2.3). TAG *In general, NAPL and other source materials should not be present when considering MNR/EMNR*.

Understanding and controlling sources of sediment contamination allows MNR mechanisms to reach cleanup goals. Source material present in surface sediments may migrate through sediment erosion and deposition, thus limiting the effectiveness of MNR. Although natural biodegradation of PAHs and other degradable contaminants has been documented in sediments overlying NAPL deposits, the potential upward mobility of source material constituents into the BAZ through groundwater and ebullition mechanisms must be characterized. Ebullition can be a potential pathway for oil/sheen migration from subsurface sediments; see Section 3.4.3.11.

3.4.3.6 Mobility

Mobility of contaminants, such as metals or NAPLs, is generally controlled by the solubility of the contaminant (USEPA 2005b). *MNR/EMNR may be amenable when site-specific factors or modeling reveals low natural contaminant mobility or bioavailability (see Section 3.4.3.7) of contaminants. Increased mobility, however, does not necessarily result in increased risk. When evaluating contaminant mobility, consider vertical extent of contaminant concentrations, redox conditions at various depths, deposition rate, and the exposure pathway.* For example, chemical degradation of PCBs is more likely to occur in deeper sediments rather than in the BAZ. Therefore, although this degradation may result in slightly increased mobility, it may not result in increased risk in the BAZ if the sediment bed is stable.

3.4.3.7 Bioavailability and Toxicity

Two categories of chemical processes can effectively reduce contaminant bioavailability and toxicity: sequestration and transformation. Attenuation of contaminants via sequestration (sorption, for example) is promoted through adsorption, complexation, and in situ precipitation (or co-precipitation). Transformation generally occurs through natural microbial processes that will either change a parent chemical into a less toxic metabolite (Cr(VI) → Cr(III)) or degrade a constituent through metabolic reactions (phenol → CO_2 + H_2O). The possibility of transformation into a more toxic metabolite such as methylated mercury or selenium, should also be considered.

3.4.3.8 Bioaccumulation and Biomagnification

To understand the potential for bioaccumulation and biomagnification at the site, conduct a thorough literature review of BSAFs or BCFs for contaminants of potential concern (COPCs). Based on this review, evaluate the potential for contaminant migration into biota through sediment, pore water, and the water column. Biota tissue residue data may also be available for the water body of interest (such as in state or federal databases). Literature values are not site-specific, however, so testing of tissues and environmental media should be performed to develop site-specific accumulation factors. COPC and TOC concentrations in sediment, pore-water and surface water can be used to develop site-specific BSAFs and BCFs as a line-of-evidence to support a case for MNR/EMNR. Higher trophic level receptors are often an endpoint of MNR/EMNR monitoring activities to show progress toward recovery. This should not preclude monitoring shellfish, which can also illustrate more localized trends. *In general, MNR may be more applicable if site-specific partition coefficients strongly favor partitioning into the sediment matrix (see ITRC 2011a).*

Higher, trophic-level receptors are often an endpoint of MNR/EMNR monitoring to show progress toward recovery (for example, removal of a fish advisory). As a precaution, contaminant concentrations may often fall below analytical detection limits before the endpoint is regarded as met. Both the public and other stakeholders, however, may still perceive levels of concern for downstream aquatic organisms (benthos and fish) due to contaminant transport from regional watersheds.

3.4.3.9 Transformation and Degradation

Data in the literature should be thoroughly reviewed for information regarding contaminant transformation pathways and biological or geochemical conditions under which these pathways occur. Physicochemical data (such as Eh-pH, redox/ORP, sulfides, AVS/SEM, divalent metals, TOC, DOC, and POC) should be collected to determine the presence or absence of parent compounds and transformation by-products in situ. Generally, for those COCs known to degrade, contaminant degradation rate versus recovery time should be compared. The time required for a contaminant to degrade below an acceptable level of risk should be less than the stipulated period of recovery. Processes reduce risk when the transformation product is less toxic or less bioavailable than the parent compound.

3.4.3.10 Source Identification and Control

See Section 3.4.3.5.

3.4.3.11 Ebullition

If ebullition is occurring at a site, caution should be used when selecting MNR or EMNR. A clear understanding of the potential contaminant mixing in the surficial sediment caused by ebullition is required in order for MNR or EMNR to be successful at the site.

3.4.3.12 Background

As discussed in Section 2.2 and in Section 3.4.3.5, background refers to substances, conditions, or locations that are not influenced by the releases from a site, and are usually described as either naturally occurring (consistently present in the environment but not influenced by human activity) or anthropogenic (influenced by human activity but not related to specific activities at the site). RAOs should account for background conditions and MNR progress should be measured against RAOs.

3.4.4 Land and Waterway Use

The land and waterway use characteristics described below include a variety of interrelated technical and nontechnical issues. In general, the collection of land and waterway use data is not required for MNR. Implementing EMNR may require this data, however, because EMNR has an active remedy component.

3.4.4.1 Watershed Characteristics

Watershed sources must be identified and controlled, if possible, for successful restoration, because these sources may be the limiting factor for the effectiveness of the remedial technology selected. Even though the on-site characteristics may indicate that MNR/EMNR are viable, uncontrolled off-site sources can contribute additional contaminants to the remediated site. The accumulation of watershed-derived COCs can negate the effectiveness of MNR/EMNR. Conversely, the lack of watershed sources would suggest that clean material will deposit within the site, thus increasing the effectiveness of MNR/EMNR.

3.4.4.2 Cultural and Archeological Resources

A review of cultural and archeological resources should include consideration of cultural influence, loss of traditional cultural practices by Native American tribes, or effects on historic or archeological landmarks such as grave sites. These issues fall under the items covered under the National Historic Preservation Act of 1966, Archaeological Resources Protection Act of 1970, and the Native American Graves and Repatriation Act of 1990. Since MNR does not disturb the natural environment, cultural and archeological issues are not a concern. EMNR, however, may have a component of active remediation that requires upland access to the site during implementation. In this case, cultural and archeological issues may need to be considered.

3.4.4.3 Site Access

Site access is key but is typically not an issue after remedial measures have been implemented. Since MNR does not require active remediation, this data category is mainly applicable for regular monitoring activity. Information on how the area will be used, such as anticipated recreation activities, may be warranted. For EMNR, a thin-layer cap in a shallow waterway would require temporary access to stage equipment along the shore to monitor the long-term efficacy of the remedy.

3.4.4.4 Current and Anticipated Waterway Use

The current use of the waterway does not affect the selection of the MNR remedy. EMNR may have a short-term influence on waterway use during mitigation and may slightly change bathymetry. Future uses with respect to navigation, recreation, and habitat are generally not an issue, but may need to be considered if the MNR/EMNR remedy requires that the sediment remain undisturbed. Sediment could be scoured and contaminants released if, for example, the waterway was open to heavy navigation.

3.4.4.5 Current and Anticipated Land Use

Non-invasive remedies such as MNR are not expected to affect current and anticipated land use. EMNR may have a short-term influence during mitigation activities.

3.4.4.6 Endangered Species and Habitat

Endangered species and habitat are not considered if the MNR remedy does not involve disturbance of the environment. Unique and sensitive species may need to be considered for EMNR. For example, a sensitive wetland habitat or species present in the affected area could be smothered by placement of a thin-layer cap. At the Johnson Lake site in Portland, OR (see Case Study D-17 in ITRC 2011a), a portion of the lake with the lowest concentrations of sediment contaminants was left uncapped to provide a means for threatened mussels to repopulate the newly covered portion of the lake.

As indicated in Chapter 2, this document assumes that RAOs have been established for the site. The decision-making steps described in Section 2.1 apply broadly to the remedy evaluation process and are critical to establishing the framework within which MNR/EMNR is evaluated. The following discussion focuses on the standard remedy evaluation criteria established by USEPA (1988), which, with some variations, many state cleanup programs have adopted. Relevance of remedy performance criteria to MNR/EMNR is also discussed in the following sections.

3.4.5 Protection of Human Health and the Environment

All alternatives considered in the detailed analysis stage of the FS must demonstrate that they provide protection of human health and the environment. MNR/EMNR achieves protection by allowing natural processes to reduce contaminants to protective levels. Protection should be documented by describing the mechanism pertinent to the COCs and estimating the time that will be required to adequately reduce contaminant concentrations (ITRC 2011a). Institutional controls used to reduce exposures during this time should be described as part of the protection determination.

Estimating the time required for various processes can be difficult and subject to uncertainty. These estimates generally include modeling the primary process involved based on deposition rates in the area of concern or chemical degradation kinetics. In many cases, MNR/EMNR is identified as an alternative for consideration based on data trends over time or implications derived from the contaminant distribution. For example, recent studies may indicate elevated concentrations of contaminants are already being covered by less contaminated sediment. Monitoring MNR/EMNR remedies should generally include contingencies for evaluating more active measures if the processes relied on do not have the anticipated result. Reasonable time estimates are site-specific and depend on how critical and feasible it is to control exposures during the time that natural mechanisms require to reduce risks.

3.5 Evaluation Process

3.5.1 Compliance with Applicable or Relevant and Appropriate Requirements

ARARs for MNR primarily arise with respect to chemical specific RAOs. These may include ambient water quality criteria (AWQC); however, the media to which AWQC apply (pore water, surface water, back-calculated sediment value) will vary depending on the exposures of concern (food chain versus direct toxicity) and the availability of other sediment cleanup criteria established by the state that may take precedence. Sediment sampling may require a permit or documentation that substantive requirements are met and tissue sampling typically requires a scientific collection permit from the applicable state or federal agency. EMNR options using placement of thin-layer caps require permits or documentation that substantive requirements are met and possibly local planning agencies. In some cases, equivalent cuts must be made in another location within the waterway to compensate for fill placed at the cap.

3.5.2 Short-term Effectiveness

While MNR/EMNR remedies do not immediately reduce risks, they also do not increase short-term risks. The effects of contaminated sediment on the environment continue but gradually decline over time. Some risk reduction can be achieved through implementation of institutional controls, though these mechanisms typically offer no benefit to ecological receptors.

The time required for natural processes to reduce contaminant levels should be estimated and the rate of risk reduction considered in evaluating the effectiveness of MNR/EMNR remedies. An approach based on net deposition should consider the sedimentation rate of clean sediments, whereas an approach based on degradation requires an estimation of the half-life of the COCs in sediment.

The nature and extent of the risk posed by contaminants is also a factor. For MNR/EMNR, it is viable to allow contaminants that bioaccumulate or biomagnify to remain at low levels for short periods of time if they do not pose a risk to the food chain. Depending on the risks, sites involving bioaccumulative contaminants may include some enhancement (such as thin-layer capping) to reduce exposures while the natural processes take effect. Note that EMNR alternatives may incur short-term risks associated with placement of a thin-layer cap, which can increase turbidity.

Potential effects on large regional ecosystems should also be considered, particularly for MNR options that could result in some dispersion of contaminants to sensitive areas. Bioaccumulative contaminants in trace quantities can accumulate to levels of concern in downstream areas if the rate of turnover in the receiving water body is extremely long.

3.5.3 Long-term Effectiveness

Long-term effectiveness is perhaps the key evaluation criteria for MNR/EMNR due to the lack of short-term impacts, the relative ease of implementation, and the low cost. The long-term effectiveness of MNR/EMNR remedies is high where site conditions are stable and the processes relied upon to achieve protection are unlikely to be reversed. Decreasing trends in contaminant concentrations, measured in the tissue of organisms collected at the site that can be linked to natural reductions in the bioavailability of contaminants in sediments, is strong evidence of the long-term effectiveness of MNR/EMNR. Episodic events (flooding or seismic activity) that disturb sediment at a site must be considered for remedies that rely on natural burial. The long-term stability of physical, chemical, or biological transformations that form the basis for some MNR/EMNR remedies must also consider seasonal changes. Changes in physical processes, such as groundwater gradient or flow rate, must also be considered where advection of contaminants through overlying sediments may be an issue. As discussed in Section , potential ramifications of leaving contaminants in place include effects on downstream resources where any contamination that migrates may accumulate. Potential effects of releases occurring during episodic events and dissolved phase transport through overlying sediment should be considered in terms of the regional ecosystem.

3.5.4 Implementability

MNR remedies are more easily implemented than other options and generally do not require construction other than signage and public outreach activities associated with institutional controls. EMNR remedies require some active measures during placement of a thin-layer cap or while modifying the sediment environment. As with standard capping, the placement of a thin-layer cap can disturb underlying contaminated sediment. Furthermore, methods used to gently place thin-layer caps can create significant turbidity, especially when the cap material includes some proportion of organic material; even levels lower than 0.5% TOC can be problematic.

The implementability of long-term monitoring programs should be considered when evaluating MNR/EMNR. Detecting long-term reductions in sediment and tissue concentrations may be hindered by spatial heterogeneity, variations in bioavailability, and seasonal and climatic factors that may influence chemical concentrations in the media being monitored (see Section 3.6 for additional discussion regarding monitoring). Reliability of MNR/EMNR options can be uncertain when rates of natural processes are not well defined or environments are unstable. More intensive monitoring may be required in these cases.

Water depth and future site uses that may reverse the containment of contaminated sediment should be considered. For example, the ability to restrict activities that will disturb sediment covers (such as recreational watercraft) must be considered and used to develop adequate institutional controls where warranted.

Unlike some capping options, MNR/EMNR remedies do not preclude implementing alternative approaches if monitoring indicates the processes selected are not effective.

3.5.5 Reduction of Toxicity, Mobility, or Volume through Treatment

Since no active treatment occurs with MNR/EMNR remedies, reduction of risk through active treatment is generally not applicable. Where a significant toxicity or mobility reduction is achieved through natural degradation processes (or additional sorptive material), however, some treatment credit can be given. Typically at sites, or portions of sites, where principal threats are present and where high-level risk is indicated, MNR/EMNR remedies will generally not be appropriate on their own. These remedies may be appropriate, however, in combination with active remedial measures.

3.5.6 Cost

MNR is generally considered an attractive option due to the low cost involved. Costs incurred with MNR include: institutional controls, long-term monitoring to ensure that natural processes are working as predicted, and monitoring to ensure that, once protective levels are achieved, the conditions associated with those levels will be stable over time. EMNR options include these costs, as well as capital costs associated with thin-layer capping or addition of sorptive media.

3.5.7 State Regulatory Acceptance

State regulatory acceptance for MNR/EMNR actions can be critical as states generally own submerged lands. Many states prefer that sediment be actively remediated so activities are not restricted in the area. States may be concerned about associated economic impacts and reduced property values if contaminants remain at levels that present an unacceptable risk for several years. Coordination with the appropriate state land and natural resources departments early in the project is necessary to identify and address their concerns.

3.5.8 Tribal Regulatory Acceptance

As with state regulatory agencies, it is important to coordinate early with local tribes who often rely on fishing resources to a greater extent than other populations. With bioaccumulative COCs, acceptable concentrations in fish may be lower because tribal fish ingestion rates may be higher than those used to estimate risk for recreational fishing. The time estimated for achieving protective levels estimated for this scenario will thus be much longer. See Chapter 8 for additional information on tribal stakeholder issues.

3.5.9 Community Acceptance

Cleanup actions that involve little more than monitoring are often difficult to justify to communities that want resources restored more quickly or may suspect that MNR is merely a form of doing nothing. If disruption due to off-site transport and disposal is not an issue, communities typically prefer that contaminated material be dredged and removed from the area; however, no remedial technology can remove all contaminants from a sediment site. Any remedy that leaves site contaminants in place has some risk of continuing exposure or re-exposure of buried contaminants.

When MNR is based primarily on natural burial, some risk exists for buried contaminants to be re-exposed or dispersed if the sediment bed is significantly disturbed by unexpectedly strong natural forces (such as ice scour or flood events), through human activities (boating, dredging, or construction), or by groundwater advection. Informing the public about the tradeoff between risks and benefits associated with the contaminants if a) they are to be left in place; b) they are to be capped; or c) they are to be removed using invasive methods is key in creating support for the MNR decision. Multiple lines of evidence are necessary to establish the expected permanence of an MNR remedy in order to achieve remedy acceptance.

Project managers should devote adequate time to explaining the processes that are at work to reduce contaminant levels naturally and the associated benefits over more invasive methods. Watershed councils and fishing groups are particularly interested, and focused outreach to these groups is helpful in gaining community support.

3.5.10 Green and Sustainable Remediation

MNR/EMNR is likely to be the greenest and most sustainable alternative evaluated for sediment sites because it involves minimal equipment and no hauling or treatment of contaminated material. Releases associated with periodic sampling events are minimal and are likely required to some extent for other remedial options as well (see ITRC 2011b for more information on green and sustainable remediation).

3.5.11 Habitat and Resource Restoration

MNR, and to a large extent EMNR, are conducive to restoring habitat because they rely on processes that occur naturally in the system and do not destroy existing habitat. The time required for restoring resources such as fisheries, however, will likely be longer for these options than for other alternatives.

3.5.12 Future Land and Waterway Use

As discussed in earlier sections, MNR/EMNR options that rely on deposition of clean material over contaminated sediments are not feasible in waterways where a particular channel depth that would extend into the contaminated layer must be maintained. MNR/EMNR alternatives generally require that site use be relatively stable and uses of adjacent upland properties would be unlikely to change depositional characteristics in the affected area.

3.6 Monitoring

Monitoring is a fundamental part of an MNR/EMNR remedy. Baseline monitoring establishes the current conditions and documents any natural recovery processes present at the site. For EMNR remedies, construction monitoring is implemented following the remedy implementation to determine whether design criteria have been achieved. Future data trends are compared to baseline conditions during long-term or post-remediation monitoring. Post-remediation monitoring evaluates natural recovery or enhanced natural recovery performance, and verifies the effectiveness in attaining remedial goals. Table 3-1 summarizes the monitoring used for MNR or EMNR.

Table 3-1. Monitoring phases for MNR and EMNR

Objectives	Measures		
	Chemical	Physical	Biological
Construction Phase			
Construction monitoring is applicable to EMNR and typically includes monitoring during placement of thin-layer caps to ensure turbidity standards established in the applicable permit are achieved. Construction monitoring also includes monitoring cap thickness during or immediately following implementation of the remedy to determine whether design criteria have been achieved.	NA	• thin-layer cap thickness • turbidity • TSS	NA

Objectives	Measures		
Post-remediation Phase			
Performance			
Performance monitoring is not applicable to MNR/EMNR. MNR/EMNR requires measurement of recovery over the long-term and not immediately following remedy implementation.	NA	NA	NA
Effectiveness			
Monitoring to determine whether COC concentrations in affected media meet RAOs, or continue to decrease and are expected to meet RAOs in an acceptable time frame.	Depends on RAOs, but may include COC concentrations in: • surface sediment • pore water • fish/shellfish • benthos	Bathymetry survey to demonstrate sediment deposition or sediment/thin-layer cap stability	Depends on RAOs, but may include: • Benthic reproductive, growth, and survival toxicity tests • Benthic community survey
Note: NA = Not applicable			

3.6.1 Baseline Monitoring

Baseline monitoring (Section 7.1) is used in the characterization of pre-remedy conditions and processes. Baseline conditions might be established as part of the sampling conducted during the RI/FS. This information can also be complemented with historical data or additional sampling to establish a complete data set. Baseline data can be compared to past conditions to determine historical trends, and can be used to develop model predictions of future site conditions. The baseline study is used as a benchmark to compare against contaminant levels measured during post-remediation monitoring, and must be qualitatively comparable to future data sets and model predictions.

3.6.2 Construction Monitoring

Baseline and performance monitoring apply to both MNR and EMNR; however, construction monitoring only applies to an EMNR remedy. Construction monitoring typically takes place during or immediately following implementation of the remedy to determine whether design criteria have been achieved. For example, if a thin-layer cap is placed as part of an EMNR remedy, the thickness of the placed cap will be measured. These measurements may be conducted through sediment cores that are collected following the placement of the thin-layer cap, or through the use of sediment pans. Sediment pans are used prior to cap placement, and following cap placement the pans are retrieved and the thickness of the collected material is measured. In addition, any potential effects from remedy implementation, such as an increase in turbidity of the water column, may also be measured as part of construction monitoring for an EMNR remedy.

3.6.3 Post-remediation Monitoring

For MNR/EMNR remedies, post-remediation monitoring is conducted to determine rates of recovery and if contaminant levels have or will reach cleanup goals in an adequate time frame. Post-remediation monitoring should be continued until remedy stability and permanence is confirmed, or the risk reduction is certain. Monitoring data should be collected over many years and, if possible, several seasons per year. Given significant uncertainties in the data, substantial spatial and temporal data sets may be needed to establish reliable trends (USEPA 2005a). Sediment profile imaging is an ideal tool to use for post-remediation monitoring because it allows direct visualization of both physical parameters (such as grain size, sediment accretion, and redox zone) and biological recovery (bioturbation zone, benthic organisms). Once remedial goals are met, monitoring might be reduced to low-frequency, disturbance-based monitoring. If it is determined that the remedy is permanently protective of human and ecological health, the site may be closed. It will likely be necessary to include institutional controls to ensure that future activities do not adversely impact the intended recovery.

Post-remediation monitoring is used to demonstrate success of an MNR/EMNR remedy. Typical trends used to determine success are listed below. Elements of these trends are further discussed in the next section.

- long-term decreasing trend in sediment contaminant concentrations
- long-term decreasing trend of contaminant levels in higher trophic level organisms
- long-term decreasing trends of pore-water chemical concentrations in the surface sediment
- long-term reduction in toxicity test performed on surface water, sediment, or pore water

If post-remediation monitoring demonstrates that remedial goals will not be met in an acceptable time, an alternative remedy should be considered. In addition, other aspects of the monitoring plan may need to be adjusted if it is determined that the data are not sufficient to establish trends with sufficient certainty.

3.6.4 Post-remediation Monitoring Program Design

The *Monitored Natural Recovery Technical Guidance Document* (ESTCP 2009 and SPAWAR 2010) identifies specific elements of the monitoring design process for an MNR remedy. These elements can also be applied to an EMNR remedy. Monitoring elements and examples from the MNR guidance document are summarized below:

- Identify monitoring objectives: Monitoring objectives assess the performance of natural recovery processes and verify attainment of cleanup levels.

  Example: Determine whether site-specific physical isolation processes continue to be sufficient to meet remedial goals.

- Develop monitoring plan hypothesis: Monitoring plan hypotheses should relate to the effectiveness of natural recovery processes in attaining remedial goals.

  Example: The sediment deposition rate is sufficient to achieve surface sediment concentration goals within a predetermined time.

- Formulate monitoring decision rules: Decision rules define circumstances where the decision maker should continue, stop, or modify the monitoring activity.

  Example: If lines of evidence conflict, give greater weight to the line of evidence that is more closely related to RAOs (for instance, if fish tissue contaminant concentrations are declining despite lower sediment deposition than predicted, the site may still be progressing toward remedial goal attainment).

- Design the monitoring plan: The monitoring plan describes data needs, monitoring elements, and data analysis methods as required by the hypotheses and decision rules.

  Example: Monitoring elements that supply lines of evidence for a sedimentation hypothesis include bathymetric mapping, sediment stability measurements, geochronology assessment, chemical and geophysical profiling, and sediment sampling. Post-remediation monitoring may include a subset of measurements, such as bathymetric mapping and surface sediment chemistry monitoring, to verify ongoing net deposition and declining surface sediment concentrations with time.

- Monitoring data analysis: Includes data collection, data analysis, the evaluation of results, and assessment of uncertainty. Example: Monitoring data are analyzed to determine sedimentation rates and changes in surface sediment contaminant concentrations in order to assess the progress toward attainment of cleanup levels.

- Establish the management decision: Progress towards remedial goals is evaluated to determine whether changes in monitoring or the remedial strategy is necessary.

  Example: If monitoring data, analysis, and decision rules support the predicted attainment of surface-sediment concentration goals within the expected time frame, this data could support a decision to reduce monitoring frequency and maintain support for the MNR remedy.

3.6.5 Monitoring Elements

The media and elements monitored as part of an MNR/EMNR monitoring plan depend on the site-specific RAOs and the physical, chemical, and biological processes that have been identified to achieve the remedial goals and cleanup levels. Monitoring elements as part of an MNR/EMNR remedy may include the following:

- Concentration data for contaminants in surface sediments demonstrate whether 1) risk to humans via direct contact is present; 2) sediments are stable; and 3) source control is adequate.
- Concentration data for contaminants in fish and shellfish demonstrate whether a direct ecological risk is present for human consumption.
- Concentration data for contaminants in pore water and reproductive, growth, and survival toxicity tests demonstrate whether the surface sediment is non-toxic to benthos.
- Benthic infauna survey data demonstrate whether surface sediments have been recolonized and support a diverse benthic community.
- Bathymetric survey data demonstrate whether sediments are a) changing due to accretion of deposited sediment or b) stable and not scoured over time or during high flow conditions.

3.7 Case Studies for MNR and EMNR

The following table summarizes case studies that describe the use of MNR or EMNR as a primary treatment remedy. Appendix A includes more details on remedies (Table A-1) and specific contaminants (Table A-2).

Table 3-2. Case studies using MNR or EMNR

Case Study, Appendix A	Contaminant	Site Description	MNR/EMNR
Hooker Chemical, Niagara Falls, NY	PAHs	River	MNR
Bellingham Bay, WA	Hg,4 methylphenol, phenols	Marine Embayment	MNR
Columbia Slough, OR	Stormwater, DDT/DDE, dieldrin, dioxins, PCBs, Pb	Freshwater Slough	MNR
Commencement Bay, WA	Metals, PCBs, PAHs, VOCs, phthalates	Marine Embayment	MNR
Koppers Co. Former Barge Canal, Charleston, SC	PAHs, arsenic, dioxin, PCP, metals	Marine Embayment	MNR
Fox River & Green Bay, WI	PCBs, dioxins, furans, pesticides, metals (Hg)	Freshwater River and Embayment	MNR
Hackensack River, NJ	Chromium	Estuary	MNR
Lavaca Bay, TX	Hg, Methylmercury, PAHs,	Estuarine embayment	MNR
Manistique River & Harbor, MI	PCBs	Tidal River Environment	MNR
Milltown Reservoir, MT	Metals	Freshwater Reservoir	MNR
Sheboygan River & Harbor, WI	PCBs	River and Harbor	MNR
Shiawassee River, MI	PCBs	River	MNR
Torch Lake Superfund Site, MI	Metals, PAHs, PCBs, phthalates, coal tar, nitrates, ammonia compounds, explosives contaminants	Freshwater Lake	MNR

Table 3-2. Case studies using MNR or EMNR

Case Study, Appendix A	Contaminant	Site Description	MNR/EMNR
Twelve Mile Creek/Lake Hartwell, SC	PCBs,	Freshwater Lake	MNR
Vineland Chemical, NJ	Arsenic	Marsh/wetland/floodplain	MNR
Wyckoff-Eagle Harbor, Bainbridge Island, WA	Creosote, PCP, PAHs, metals	Subtidal and Intertidal	MNR
Zidell – Willamette River, OR	PCBs, metals, PAHs, TBT	River	MNR
Bremerton Naval Yard OU B, WA	PCBs, Hg	Marine Embayment	EMNR
Ketchikan Pulp, AK	Arsenic, metals, PCBs, ammonium compounds, 4 methylphenol, H_2S	Marine Cove	EMNR

4.0 IN SITU TREATMENT

In situ sediment treatment involves applying or mixing of an amendment into sediments. Mixing may be achieved either passively, through natural biological processes such as bioturbation, or actively through mechanical means (using augers, for instance). For the purposes of this guidance, in situ treatment includes only those technologies that mix amendments into sediments. This approach differs from capping, in which treatment amendments are placed as a distinct layer above the sediment and the contaminants are treated as they migrate upwards through the treatment zone (see Chapter 5). In situ treatment technologies can achieve risk reduction in environmentally sensitive environments such as wetlands and submerged aquatic vegetation (SAV) habitats, where sediment removal or containment by capping might be harmful. Treatment amendments typically reduce concentrations of freely dissolved chemicals (termed "C_{free}") that are available for exposure to organisms or that may be mobilized and transferred from sediment to the overlying water column. Reducing C_{free} in sediment pore water through sorption (sequestration) or degradation lowers exposure and risk.

4.1 In Situ Treatment Background Information

In situ treatment, when viable, has emerged as an improvement over the remedial performance of MNR/EMNR and removal technologies. Thus, many of the site factors evaluated when selecting these technologies are also relevant to in situ treatment. Treatment amendments may be preferred in areas with higher contaminant concentrations, where MNR/EMNR cannot achieve risk goals in an acceptable time or where immediate risk reduction is needed. In situ treatment is also a means of managing exposures associated with residuals that remain following the removal of sediments.

While various amendments can target different types of contaminants in sediment, AC is one of the most widely used for in situ immobilization (Ghosh et al. 2011). Bench-scale data suggests that pore-water concentrations and bioavailability of hydrophobic contaminants can be reduced between 70% and 99% at AC doses similar to the native organic carbon content of sediment. Based on these results, over 25 field-scale demonstration projects spanning a range of environmental conditions are now underway or nearing completion in the United States and Norway (Patmont et al. 2013). These projects have demonstrated the efficacy of full-scale in situ sediment immobilization treatment technologies to reduce the bioavailability and mobility of a range of organic and metal contaminants, including PCBs, PAHs, dimethyl dioxane, dioxins/furans, chlorinated benzenes, tributyltin (TBT), and mercury. A wide range of AC placement options has been demonstrated at the field scale, including:

- direct application of amendments, with or without binder and weighting agents
- mixing amendments with sediment or sand prior to placement
- placement of amendments below covers or caps (see Chapter 5)

In situ immobilization treatment can be a permanent sediment cleanup remedy that rapidly and sustainably addresses key exposures (such as bioaccumulation in fish) and may become more effective over time, since sorption does not reach equilibrium immediately and complete mixing of amendments with the sediment may take time. In situ treatment can be less energy intensive (less material used and transported), less disruptive to the environment (certain in situ technologies do not damage the habitat, whereas capping and dredging always do), and less expensive than conventional remedial technologies such as dredging and capping. This technology can also significantly reduce ecosystem exposure by binding contaminants to organic or inorganic sediment matrices.

Through adsorption, in situ treatment with AC reduces biota and human exposures to many contaminants. AC can adsorb PCBs, which are one of the most common contaminant groups driving risk at sediment sites. AC can also be mixed with other amendments such as organophilic clay, zeolites, bauxite, and iron oxide/hydroxide to bind additional contaminants in the sediments. Other amendments, such as apatite, nutrients or ozone (for biostimulation), KB-1 (for bioaugmentation), and zero valent iron (ZVI), are specifically designed to degrade chemicals or transform them into less toxic forms (O'Day and Vlassopoulos 2010).

Theoretically, once molecules of chemicals such as PCBs are bound to a sorbent such as AC, the exposure potential of that chemical is negligible. Unlike organic carbon, the sorbent AC is not readily broken down in the environment and the binding remains strong, based on thermodynamic principles, resulting in a high confidence in the short-term and long-term fate of the bound chemicals. The chemicals are expected to remain bound whether the sorbent and bound chemicals remain in the sediment bed or are resuspended and transported away from the area. Studies may be needed on a site-specific basis, however, to confirm that this theoretical assumption holds true in the field. Currently, few long-term studies on in situ effectiveness are available because the technology is still relatively new.

Other amendments such as cement and cement with lime or fly ash can physically solidify or stabilize contaminants (see Table 4-1). This in situ solidification approach can be applied to higher concentrations of contaminants, but is considered a more active and invasive form of treatment. Treatment amendments that immobilize or degrade contaminants within the sediments address concerns that may be raised about leaving contaminants in place.

With a growing emphasis on sustainability, in situ treatment remedies offer an opportunity to realize significant environmental benefits while avoiding the environmental damage associated with more invasive remedial technologies. Three key benefits of sustainability associated with in situ treatment include:

1. *Environmental*. In situ treatment can accomplish destruction of contaminants in some cases, which is typically preferable to nontreatment alternatives. Alternatively, in situ treatment can achieve near-immediate reduction of the bioavailable fraction of contaminants (thus reducing exposure to contaminants) with minimal effects on habitat, leading to a potentially shorter ecological recovery time as compared to other alternatives. In situ treatment often requires less energy and material usage and results in lower emissions (carbon and other) than other

active remedies.

2. *Economic*. In situ treatment is typically a cost-effective way to rapidly return the system to economic and ecological productivity (such as restoring tourism and fisheries). The costs associated with implementation are likely to be lower than capping or dredging.
3. *Social*. In situ treatment results in reduced risk to workers and fewer effects on the community (compared to capping and dredging). The potential also exists for faster restoration of recreational and aesthetic resources than occurs with MNR. In situ treatment also reduces adverse effects on the community associated with long-term remedial projects, such as noise, truck traffic, and fumes.

Finally, while in situ treatment is commonly used for treating contaminated soil and groundwater (USEPA 2006a), the use of in situ treatment for sediments is still an emerging technology. The success and promise of this technology, particularly in situ immobilization treatment using AC, has been demonstrated primarily through a number of bench-scale treatability studies and field-scale pilot projects (Patmont et al. 2013). A limited number of full-scale implementations of in situ treatment have been applied at relatively small sites, but larger-scale applications are being planned or are currently underway in the U.S. and Norway. In situ demonstration projects are underway in several USEPA regions and in situ projects are gaining interest and funding from USEPA, state agencies, DOD, the Superfund Research Program, and private industry.

The following sections provide information necessary to evaluate in situ treatment as a remedial technology on a site-specific basis. Some of the information included in these sections is considered theoretical because some types of treatment have not yet been applied to sediments in the field. Information available from real-world applications is included where it is available. For a summary of the some of the most promising in situ treatment technologies, see *Use of Amendments for In Situ Remediation at Superfund Sediment Sites* (USEPA 2013a), which provides information on the state of the practice for this technology and presents three case studies describing sites where amendments have been used.

4.2 In Situ Treatment Objectives and Approaches

The design of any in situ treatment application must address two key issues: treatment amendments (materials) and delivery system (method). The following section summarizes general types of treatment amendments and delivery methods and provides information on the development status of each method.

4.2.1 Materials for Treatment Amendments

In situ treatment approaches can be grouped into the categories listed below; see Table 4-1 and Table 4-2 for the development stage of each of these technologies (bench, pilot, or full scale):

Biological

- *Bioaugmentation* is the addition of cultured microorganisms directly on or into the sediment to degrade and transform specific contaminants. For example, although not common for in situ sediment treatment, KB-1 is a commercially available culture for treatment of certain chlorinated solvents.
- *Biostimulation* is the enhancement of rate-limiting sediment conditions in order to stimulate the indigenous microorganisms to degrade and transform specific contaminants (for instance, through oxidation).
- *Inhibition* occurs when amendments are added to inhibit biological processes that would normally cause contaminants to be transformed into more toxic forms under existing conditions. For example, applying nitrate can inhibit the release of methylmercury.

Chemical

- *Transformation* results from the addition of specific chemical admixtures (such as apatite) to alter the contaminant to less toxic or bioavailable forms.
- *Degradation* results from the addition of specific chemical mixtures to decompose the contaminant to less toxic or bioavailable forms (for example, ZVI can degrade certain chlorinated VOCs).

Physical

- *Sorption* results from the addition of chemicals or other materials (such as AC, organophilic clay, zeolites, bauxite, and iron oxide/hydroxide) that physically or chemically bind (adsorb) contaminants to reduce their bioavailability. Application of AC is the most widely used and tested of these techniques (Patmont et al. 2013).
- *Stabilization/solidification* involves the addition of chemicals or cements (such as Portland cement, quicklime, and fly ash) to encapsulate contaminated sediments into a solidified mass that reduces contaminant mobility and bioavailability.

Combination

- In practice, the application of in situ treatment can incorporate combinations of the above as well as other remedial technologies including dredging, capping, and MNR. For example, in situ treatment can be used below a cap or combined with EMNR to accelerate ecosystem recovery.

4.2.2 Delivery of Amendments

In order to be successful, in situ sediment treatment must achieve adequate contact between treatment amendments and the contaminants. Factors involved in achieving this contact include:

1. *Sediment stability*. Sediment stability information helps site managers to judge whether an in situ remedy will be effective and what additional design is needed to secure the treatment

amendments in place. For in situ treatment, low-energy environments are generally more suitable than high-energy environments. Examples of suitable environments include wetlands, vernal pools, ponds, embayments, and harbors that are depositional with low likelihood of highly erosive events. The stability of an in situ treatment can be increased for high-energy environments by modifying the physical characteristics of the amendment and by incorporating the amendment into an EMNR technology designed to withstand higher shear stress.
2. *Amendment placement location*. Amendments can be either mechanically dropped into place at the surface of the water column or sprayed onto the surface. Amendments then settle through the water column to the sediment surface. Alternatively, some delivery systems use a boat or barge to drag a machine that injects amendments directly into the sediment. Key delivery issues include achieving the desired treatment dose over the required area while minimizing losses to adjacent areas outside of the treatment zone. Water depth, waves, and currents are key hydrodynamic characteristics that must be accounted for in order to achieve the desired placement (for instance, by designing amendments with adequate density to settle through the water column). To some extent, these same factors must be considered when implementing an EMNR or a capping technology. Experience and expertise with those technologies can be applied to in situ treatment technologies.
3. *Mixing method*. Mixing of the amendment and sediment can be accomplished actively and mechanically (for example, by using augers) or passively by relying on natural biological process (for example, bioturbation by benthic organisms) and physical processes (such as gravity).

A summary of some in situ treatment technologies (amendments and delivery systems) that have been implemented in the field at pilot or full scale is provided in Table 4-1. These technologies are relatively mature and are likely to be effective. Table 4-2 provides information about treatment techniques that have been tested only in laboratory studies to date. These techniques may require more in-depth study (such as additional bench-scale tests or field pilot tests) before selecting them as a remedy.

Table 4-1. Use of in situ technologies for sediments (field demonstrations at full or pilot-scale)

In situ Technology and References	Treatment	Technical Basis	Contaminant Applicability	Application	Development Stage	Comments
Amendments						
Biostimulation (oxidation) (Golder Associates 2003)	Biological - Biostimulation	Aerobic degradation of organic contaminants through introduction of oxidants such as calcium nitrate or sodium nitrate	PAHs, BTEX compounds and TPH	Marine and Freshwater	Several pilot scale and full scale projects implemented	
AC Amendments (Ghosh, Zimmerman, and Luthy 2003; Cho et al. 2009; Beckingham and Ghosh 2011; Ghosh et al. 2011; Patmont 2013)	Physical – Sorption	Deployment of various carbon options including AC, coke, black carbon/charcoal that strongly sorb organics and inorganics	Hydrophobic organics and metals: PCBs, PAHs, dioxins, pesticides, mercury	Marine and Freshwater	Laboratory studies and field pilots; several full-scale applications currently underway	
Organophilic clay (Knox Et al 2011; Arias-Thode and Yolanda 2010)	Physical - Sorption	Sorbing amendment for organic compounds and organically complexed metals	Sorption of organics and organically complexed metals (such as methylmercury)	Marine and Freshwater	Laboratory studies; has been incorporated into sediment caps full scale; may also be used as an amendment in situ	

In situ Technology and References	Treatment	Technical Basis	Contaminant Applicability	Application	Development Stage	Comments
Apatite (calcium phosphate mineral) (Knox et al. 2008 ; Williams et al. 2011; Scheckel et al. 2011)	Chemical Reaction - Transformation	Apatite reaction with metals to form phosphate minerals that sequester the divalent metals and reduce toxicity to aquatic organisms by reducing bioavailability	Cd, Co, Hg, Ni, Pb, Zn, and U	Marine and Freshwater	Pilot test in Chopawamsic Creek, VA, sediments. multiple successful laboratory studies	Short reaction time (on the order of weeks); can enhance desorption of As, Se, and Th; reactions sensitive to redox conditions.
Delivery systems						
Limnofix In situ Sediment Treatment Technology (Golder Associates 2003)	Mechanically mixed/injected	Amendments introduced through a series of tines and nozzles on an injection boom	Generally used to apply oxidative amendments (calcium nitrate) for biodegradation of PAHs, BTEX, TPH or to mitigate acute sulfide toxicity	Freshwater and Marine	Full scale applications and Field Pilots	Has been used to treat sediment to a depth of 0.5 meters (into the sediment) with water depths of 3 to 24 meters.

In situ Technology and References	Treatment	Technical Basis	Contaminant Applicability	Application	Development Stage	Comments
SediMite (Menzie-Cura and UMBC) (Menzie, personal communication 2011; Ghosh et al. 2009)	Surface placement/biologically mixed	Pelletized AC with a binding amendment tailored to contaminant of concern. Binding adds weight for emplacement on sediment bed. Benthic organisms and natural processes mix SediMite into sediments where binding eventually breaks down increasing surface area of AC	PCBs, methylmercury and other hydrophobic chemicals	Freshwater and Marine particularly in areas of sensitive environments or in hard to reach areas such as around pier structures.	Small full scale, Field Pilot Scale, and Laboratory Studies	Initial thickness of application is generally less than 1 cm.
AquaGate (AquaBlok patented) (ESTCP program, Aberdeen Proving Ground, Canal Creek, Bremerton Naval Shipyard)	Low impact AC, organoclay and other mineral delivery system	Composite particle of powder AC or other coating material tailored to a contaminant of concern. Coating materials are delivered to sediments by a high density core. Density of particle provides for mixing with sediments (mixing occurs due to gravity).	Used to date on PCBs, range of PAH, pesticides, and a range of metals.	Freshwater and Marine	Laboratory Studies and Field Pilot Scale. Full Scale applications of materials as component of active cap design.	Allows for placement of materials at greater depths; proven full-scale placement

Table 4-2. Use of in situ technologies (laboratory demonstrations only)

In situ Technology and References	Type	Technical Basis	Contaminant Applicability	Application	Stage	Comments
Amendments						
Ozonation (biostimulation) (Hong 2008)	Biological - Biostimulation Chemical - Degradation	Introduction of ozone to sediments may degrade organic compounds through first abiotic and then aerobic degradation mechanisms.	PCBs and PAHs	Marine and Freshwater	Laboratory Studies	Pressure-assisted introduction of ozone appears to be more effective than conventional ozonation.
Zero Valent Iron (ZVI) (Hadnagy and Gardener, personal communication, 2011)	Chemical - Transformation	Reductive dehalogenation using zero valent iron usually with a bimetal catalyst. Mg or Zn instead of Fe has also been shown to be effective.	Abiotic destruction of halogenated aromatic organics (such as PCBs, PCDD/F and chlorinated pesticides)	Marine and Freshwater	Laboratory Studies	Achieves destruction of contaminants. Incomplete reactions could potentially produce compounds that are more toxic than parent compounds.
Zeolites (Knox et al. 2008)	Physical - Sorption	Hydrated aluminosilicate minerals with a large open framework that forms large “cages” in the mineral structure. Cages can trap cations and even molecules.	Pb, Cu, Cd, Zn, Cr, Co, Ni	Freshwater	Laboratory Studies	Preferential exchange with Na ions over metals occurs.

In situ Technology and References	Type	Technical Basis	Contaminant Applicability	Application	Stage	Comments
Bauxite/ Bauxite Residues/"Red Mud" (Lombi et al. 2002; Gray et al. 2006; Peng et al. 2009)	Physical - Sorption	Bauxite residue (red-mud) contains both Al oxides and Fe oxides. Experiments suggest chemisorption of heavy metals to Fe oxides in the red-mud.	Heavy metals and metalloids Cd, Cu, Pb,Ni, Zn		Laboratory Studies and Soil Pilot Study	
Iron Oxides/Hydroxides (Lombi et al. 2002)	Physical - Sorption	Fe minerals such as limonite and goethite adsorb metals reducing bioavailability	Heavy metals Cd, Cu, Zn, and As	Marine and Freshwater	Laboratory Studies	
Cement with Lime or Fly Ash (Gray et al. 2006; Peng et al. 2009)	Physical- Solidification/Stabilization	Physical solidification of the media and precipitation of metal carbonates or increases pH to allow oxide formation onto which metals can sorb (stabilization)	Heavy metals Cd, Cu, Ni, Pb and Zn		Laboratory Studies and soil pilot study	

4.3 Design Considerations

If appropriate for the site conditions, in situ treatment offers a relatively low-impact remedial option that provides a high level of effectiveness. The following section describes the advantages and disadvantages of in situ treatment, as well as the design factors that should be considered for this approach.

4.3.1 Design Advantages

One primary advantage of in situ treatment is that it can accelerate sediment cleanup using low-impact methods, either on its own or when paired with MNR/EMNR. In situ treatment may, in some situations, be preferable to EMNR, capping, and removal because it may be able to achieve similar or better results with less impact. Some in situ approaches can degrade or destroy contaminants; for these treatments, the remedy evaluation should quantify the amount of contaminants that are likely to be removed from the system (similar to estimates prepared for removal by dredging).

Because in situ treatments add an otherwise foreign element to sediments (such as AC), the acceptance of this approach depends on demonstrating that the benefits of adding amendments clearly outweigh any potential negative effects. Based on evidence to date, AC shows little or no long-term negative effect on sediments, thus its benefits usually outweigh possible harm. Other low-impact in situ treatment technologies such as SediMite, Limnofix, and AquaGate also deliver treatment agents without disturbing the physical characteristics of the sediments and water column (as occurs in dredging and some capping alternatives). Because physical sediment characteristics are the predominant factors influencing the community structure of benthic invertebrates, leaving these characteristics generally unchanged is a distinct advantage over remedies that add materials which change the physical characteristics of the sediment (such as some EMNR and capping technologies). In addition, low-impact in situ technologies allow for management of sediment adjacent to retaining and support structures, which are often aged and require structural analysis and support prior to dredging or removal activities. Substantial costs, which often do not directly benefit the environment, can be associated with infrastructure management on dredging projects, thus management in place may be preferred.

In situ treatment also offers the potential to provide better long-term protectiveness from recontamination than dredging or capping, because excess treatment capacity can be built into the initial sediment treatment. The long-term effectiveness of any treatment may be reduced if treatment capacity is overwhelmed by contaminants in the sediments, by new contaminants freshly mobilized from untreated sources, or by other components of the sediment system. If treatment efficacy is compromised or overwhelmed, repeat treatment or application of another remedial technology may become necessary. With in situ treatment, additional amendments can be added in the first application at a sufficient dosage to provide excess treatment capacity. This excess capacity protects the sediments from recontamination that may occur from uncontrolled sources.

In situ treatment technologies that destroy contaminants also achieve mass reduction, which is an advantage over other available sediment remediation technologies. In situ immobilization treatments that use sorbents (such as AC) act on contaminants in place, but do not degrade them and do not, on their own, achieve mass reduction. These remedies are similar to MNR/EMNR in that leaving contaminants in place is often viewed as a disadvantage relative to removal technologies. Some evidence, however, suggests that natural biodegradation can be enhanced by sorbing contaminants to AC because, although AC does not directly degrade contaminants, the carbon substrate provides a surface for microbial growth. The low biodegradation rates of recalcitrant compounds such as PCBs may result in long predicted time frames for complete degradation.

In situ treatment can be more cost effective and less environmentally damaging than dredging or capping for areas that have the requisite site and contaminant characteristics and where the concerns regarding deeper contamination (see Section 4.3.2) can be addressed. In situ treatment is especially favorable over dredging or capping for sensitive environments and where disturbances must be minimized. In these situations, in situ remedies also reduce exposures more quickly than MNR alone.

> ***One-way Degradation Processes***
>
> *Most degradation processes are one-way processes. Once a treatment agent degrades a chemical molecule, the molecule cannot be re-created and is no longer available for exposure. Treatment thus reduces the overall inventory of chemicals present. Future resuspension and transport of contaminants from the treated sediment is not a concern because of the high degree of confidence in the short-term and long-term fate of chemicals degraded through these one-way processes.*

In situ treatment approaches may be selected to reduce toxicity, mobility, or volume of contaminants for select areas and may be favored over other approaches for specific remedial zones. For example, access, water depth, or habitat-related issues may preclude some treatment alternatives. Dredging under bridges, piers, or against bulkhead walls may leave areas where significant residual contamination may exist after, or as a result of, remediation activity. In situ treatment may provide a means to enhance the overall remediation effort for these residual areas.

4.3.2 Design Limitations

One challenge to gaining acceptance for in situ treatment is the lack of full-scale, completed projects using this technology. While the results from numerous pilot studies are encouraging, remedies that have been used in full-scale applications are more readily accepted. This situation arises for many new technologies and should not preclude the use of in situ treatment, especially given the many potential advantages that this approach offers.

Another design limitation is that some in situ technologies treat only surficial sediments, leaving deeper contamination untreated. While this approach is not a limitation if sediments are stable, it is possible for contamination remaining in deeper sediments to become exposed following a storm or as a result of contaminant migration to the surface. This issue, which also arises with MNR/EMNR, can be addressed during the design phase with estimates of long-term performance and design adjustments as needed.

Uncertainty about future site activities, such as construction projects or navigational dredging, can also lead to concerns about leaving deeper contamination in place. These concerns can be addressed through institutional controls and through memoranda of understanding regarding actions that must be taken if conditions change. Concerns about long-term performance can lead to requirements for intensive long-term monitoring programs, which can be costly and may offset some of the savings that would otherwise be realized with in situ treatment. Site owners or other potentially responsible parties may also be concerned about the future liability associated with buried, untreated sediment.

4.3.3 Additional Design Considerations

Several in situ pilot studies and full-scale applications of soil and sediment remediation have been conducted in the field (see Table 4-1). These studies have evaluated feasibility in a wide range of environmental conditions including marine mudflats, freshwater rivers, estuarine marshes, tidally influenced creeks, and open ocean harbors (Patmont et al. 2013). The following sections provide a summary of key design factors developed in these applications.

4.3.3.1 Selection of Appropriate Criteria for Success.

An in situ treatment option that leaves contaminants behind requires monitoring to confirm the effectiveness of the remedy. The monitoring methods must evaluate the effectiveness of the remedy and should discriminate between exposure from the treated site versus exposure from untreated, off-site sources. This differentiation is challenging at sites where uncertainty remains regarding the extent and contribution from different sources of exposure. For example, at many sites high levels of bioaccumulative chemicals (such as PCBs and mercury) in fish are the primary risk drivers for the remedy. Tracking effectiveness based on pollutants in animals at the top of the food chain, however, may be difficult if ongoing sources of pollution contribute to the exposure. In this case, selecting a success metric that narrowly targets specific uptake pathways to fish from the treated sediments may be more appropriate. Additional examples of effective criteria include measurement of pollutants in native benthic animals, pore water of treated sediments, and flux from sediment into the water column.

4.3.3.2 Accumulation of New Sediment Deposits

Sites contaminated with legacy chemicals are typically in historically depositional environments, thus deposition of new sediments is expected to continue after the remedy is implemented. Planning for post-remedial monitoring must consider these new sediment deposits. For example, if an amendment is placed on surface sediments and is tracked over time, a gradual decline in the levels of the amendment on the surface may be observed. The interpretation of this observation, however, must account for new sediment deposition at the site, especially from major weather events, which can potentially deposit several inches of new sediment in a short time. Accurate bathymetry measurements are useful in keeping track of sediment deposition. As with other technologies, if the newly deposited sediments are contaminated (for example, with PAHs from urban runoff), the effectiveness of the remedy may appear to decrease with time.

4.3.3.3 Site Heterogeneity

Heterogeneity in site conditions and contaminant levels can sometimes confound monitoring results. Adequate density of sampling should be performed to capture site heterogeneity and inform remedy design. The sampling plan for effectiveness monitoring should have sufficient statistical power to adequately track changes over time.

4.3.3.4 Application Heterogeneity

Application of in situ amendments is typically at a low dosing rate and results in actual surface coverage that is often less than 1 inch. At this application rate, a uniform surface coverage in the field can be difficult to achieve. AC placement at uniform levels has now been demonstrated using a wide range of conventional equipment and delivery systems. Uniform AC placement has also been demonstrated in relatively deep and moving water (Patmont et al. 2013). Other innovative application methods that have not been demonstrated at other sites should be tested in advance to show that uniform surface coverage can be achieved. Potential approaches for achieving uniform coverage include:

- multiple passes during one application
- multiple applications over a number of years to build up the desired dose uniformly over time with new sediment deposition
- tracking changes in water flow and direction, especially when a broadcast method is used and application is over a moving water body or over a tidal cycle

4.4 Data Needs for In Situ Treatment Design

Data collected during the development of a CSM, specifically in the RI process, are fundamental in assessing the applicability and potential performance of any sediment remediation technology. Four general categories of data are typical of CSM investigations (see Section 2.4.1): physical site characteristics, sediment characteristics, the contaminant characteristics, and land and waterway use.

4.4.1 Physical Site Characteristics

Physical site characteristics define the physical ability of the bed to support a uniform amendment application. The bed must have uniformity and stability sufficient to result in a uniform distribution and adequate mixing of the amendment. The amended sediment bed must also remain in place for an adequate time to complete and maintain the treatment. The following sections describe the key physical characteristics to consider when evaluating the potential performance of in situ treatment.

4.4.1.1 Advective Groundwater Transport

Data regarding contaminant fluxes due to advective groundwater transport are key to in situ treatment design. Advection into and through the sediment can transport contaminants into the treatment zone, either from contaminated groundwater entering the sediment system or from initially uncontaminated groundwater carrying deeper sediment contamination into shallower zones. This mechanism creates a potential ongoing source to the treatment zone and may reduce treatment efficacy over time. Note that in tidal areas, tidal oscillations can cause advective fluxes that are orders of magnitude higher at the sediment-water interface relative to the average regional flux.

Contaminant flux via groundwater is chemical specific. Site investigations conducted prior to selecting remedies typically provide information necessary for assessing additional contaminant loads expected from advective groundwater transport. When the contaminant flux can lead to unacceptable exposures if the additional contaminants are left untreated, sufficient amounts of amendments must be added to treat both existing contamination and the predicted contaminants from groundwater advective flow. *Contaminant treatment capacity must exceed the supply of contaminants from groundwater.*

4.4.1.2 Sediment and Pore-Water Geochemistry

Sediment geochemistry can be an important consideration for amendments that are designed to degrade contaminants. For example, reductive dechlorination requires anaerobic (low oxygen), highly reducing conditions to be present, while degradation of petroleum compounds typically occurs under aerobic (high oxygen), oxidizing conditions. Certain treatments are sensitive to other aspects of sediment geochemistry, including the sediment organic carbon content, sulfide concentrations, and pH.

Amendments such as AC adsorb persistent hydrophobic chemicals and can be used under a variety of geochemical conditions. The dosage needed, however, may be influenced by specific geochemical conditions that dictate the availability of contaminants. These amendments typically adsorb several orders of magnitude more contamination than natural organic carbon. A typical amendment dosage is approximately equal to F_{oc} in existing sediment, which will decrease contaminant availability by several orders of magnitude. *The sorbent must be applied in an amount sufficient to out-compete natural carbon in the sediments.*

Site-specific geochemical conditions must also be well defined in order to select an in situ treatment technology that relies on geochemical reactions or biodegradation. In addition, these treatments may change geochemical conditions, which can affect both target and nontarget contaminants. Increases in biological activity, for example, can reduce pH and thus mobilize certain metals. Similarly, metals are often bound in the sediment by sulfides, but if the treatment method selected reduces sulfide concentrations, then the metals can become more bioavailable and potentially increase the direct toxicity of the sediment. Furthermore, many contaminants can be strongly bound to organic and inorganic carbon in sediment. If the in situ treatment consumes carbon (such as addition of amendments that cause chemical oxidation of organic compounds), then certain contaminants may become more bioavailable. Sediment geochemistry also influences the native state of binding and availability of target chemicals with which in situ treatment agents (especially sorptive amendments) compete. For example, sediments with strongly sorbing native black carbon may need a higher dose of AC amendment, compared to sediments without native black carbon, to achieve the same degree of effectiveness.

4.4.1.3 Hydrodynamic Characteristics

Hydrodynamic characteristics, such as water depth and flow, influence the design and implementation of in situ treatment. In more energetic areas, in situ treatment may be used to augment EMNR, but a mechanical placement or injection method might be needed (rather than a gravity settling method) to deploy the treatment amendment. Binder and weighting agent amendments can also be added to improve gravity settling of AC through the water column (Patmont et al. 2013). *Treatment performance is influenced by the energy level and bottom shear stress, and in general, less energy and bottom shear stress is preferred for effective in situ treatment.*

Some sediment environments in embayments and tributaries can experience flash flooding following storms, which can mobilize treatment materials. In situ treatment design must consider not only average conditions, but also these periodic erosional events. For in situ treatment, the water depth affects whether equipment can be brought to the treatment area over water (if a land-based application is not selected). Water depth affects physical delivery when the water body has a flow component. For example, when treatment materials are sprayed onto the surface of the water and allowed to settle to the bottom, the materials move with the flow of the water body. If the depth to sediment is too great, treatment amendments may be dispersed beyond the targeted sediment area before they can settle (Cornelissen et al. 2012). These conditions may require delivery using subsurface delivery systems or binder and weighting agents.

4.4.1.4 Sediment Depositional Rate

Depositional rate data can indicate potential long-term recovery conditions. Ideally, in situ treatment of contaminants in sediment is an irreversible process capable of reducing contaminant concentrations to protective levels. Once this treatment is complete, the deposition of additional clean sediment serves as an additional element of recovery, but is not necessary for achieving protection goals. *A positive annual net deposition rate improves the long-term effectiveness of in situ treatment, but is not a prerequisite for the use of in situ treatment.* Note that sediment stability (Section 4.4.1.5) and erosion potential (Section 4.4.1.10) can also affect depositional rates

When in situ treatment is used for mercury contamination, deposition can eventually remove source sedimentary mercury from the zone of potential methylation. The deposited sediment layer, along with the sediment's capacity to adsorb methylmercury and ionic mercury, provides long-term remediation. If the treatment is focused on only the bioactive zone, and contaminated sediment is left untreated below, then the potential for future erosion must be evaluated to determine whether deposition can sufficiently protect underlying materials.

4.4.1.5 Sediment Stability

Sediment stability data can indicate whether the sediments are stable enough to remain in place until the treatment is complete. The efficacy of in situ treatment remedies increases with increasing sediment stability, because a minimum contact time is usually needed to achieve treatment. In situ treatments work best in low-energy environments, where the potential for erosion is minimal.

While in situ treatment can work in less stable sediments, additional design features may be needed to secure the treatment in place long enough to remediate the target contaminants.

Water velocity determines the shear stresses that affect sediment stability and scour potential. Data regarding the frequency and magnitude of potential high-velocity flooding can help to predict the associated hydrodynamic effects on in situ treatment. For example, high shear forces may prevent the in situ treatment amendment from remaining in contact with the contaminated sediments. Flooding may diminish treatment effectiveness and cause treated sediments to be resuspended and transported away from the treatment area. Treated sediments that are resuspended may be deposited in the floodplain or downstream. While no specific data suggests that these sediments could pose a risk if deposited in the floodplain, site managers should be aware of this potential issue. *For treatment processes that achieve complete destruction of contaminants (or irreversible transformation to a nontoxic form), there is little concern for future remobilization if treatment is complete at the time sediments are eroded. On the other hand, when contaminants are only sequestered, it is preferable for sediments to remain stable over time.*

Future movement of treated contaminants does not necessarily lead to unacceptable risks. For example, sequestration using AC is believed to be irreversible under normal conditions, so there is little concern over the sediment stability for this treatment. On the other hand, if future erosion leads to exposure of deeper contaminated sediments that have not been treated, then additional treatment may be required.

The treatment amendments themselves can potentially affect the sediment stability. For example, mechanical mixing while adding amendments may cause sediments to be less cohesive, and therefore more subject to erosion in the short term. Conversely, in situ solidification and stabilization of sediment can increase sediment stability, in which case the stability prior to treatment is relatively unimportant (see also slope stability, Section 4.4.1.8, and resuspension potential, Section 4.4.2.4).

4.4.1.6 In-water and Shoreline Infrastructure

Information describing current or historical in-water and shoreline infrastructure can be obtained from local agencies, as well as developed from site-specific data collected while visually inspecting the site. In situ treatment can be an effective alternative in some cases for contaminated sediments located adjacent to or beneath structures such as piers. Because in situ treatment does not remove sediment, this approach does not compromise support for structures relying on sediment for their stability. By comparison, accessing sediment beneath piers, for example, can be time consuming and costly if dredging or directly injecting or mechanically mixing sediment amendments (such as auger mixing for stabilization/solidification). Additionally, most in situ treatments do not change the existing bathymetry, and thus lessen influences on currents and waves. *Although in situ treatment may require less access than other technologies (such as removal) some direct access is needed (either for placement of amendments or for monitoring/sampling activities). Implementability of in situ treatment decreases as the amount of in-water and shoreline infrastructure increases, unless the infrastructure does not hamper placement of amendments on or into the sediment.*

Infrastructure data can also help to guide in situ treatment applications that spray amendments onto the surface of the water and use gravitational settling to the bottom to place amendments. These treatments can sometimes reach sediments beneath, and immediately adjacent to, in-water structures where dredging and capping are difficult. Accurate delivery and placement methods are improving, and in situ treatment is becoming applicable to a wider range of environments where infrastructure is present.

4.4.1.7 Hard Bottom and Debris

The presence of a hard bottom or debris in sediments is typically not a constraint for in situ remedies that target contaminants in surficial sediments. Usually, the treatment amendment is placed on the sediment surface and mixing occurs naturally; a hard bottom or debris has little effect on this process. Some applications, however, rely on shallow mixing of sediment or injection of amendments directly into the subsurface and debris or a hard bottom can interfere with these processes. When bedrock, cobble, or other forms of hard bottom exist beneath the sediment to be treated, evaluate the amount of mixing required in order to determine whether objectives can be achieved.

4.4.1.8 Slope Stability

Slope stability data is needed because placing treatment materials on slopes may result in instability (see Section 3.4.1.8). The slope stability factor of safety should be greater than 1.5. Slope stability calculations are recommended when the slope is greater than 5% or when the sediment shear strength is less than 1 kPa (20 psf). For in situ treatments, these loads are relatively light compared to thicker containment caps. *Placement of amendments on the surface of the sediment, for passive incorporation/mixing into the sediment, may not be effective if amendments do not remain in place due to poor slope stability*. AC has been effectively placed at slopes as steep as 50% or 2H:1V (Patmont et al. 2013). The sediment must have sufficient strength (bearing capacity) to support the weight of amendment material without lateral displacement (mud waves) of the sediment under the cover (see Section 5.4.1.6).

4.4.1.9 Water Depth and Bathymetry

The water depth and specific bottom bathymetry data are necessary for the selection and design of in situ sediment treatment. Most in situ treatment studies in the United States have been conducted in shallow waters (less than 3 m) and wetlands, but trials in Norway have applied in situ treatment agents to sediments under water depths of up to 100 m in contaminated fjords (Cornelissen et al. 2012). If conventional mechanical equipment is used to deliver treatment amendments and to mix the sediment and amendments together, then the length of the equipment and desired thickness of sediment to be treated dictate the maximum water depth at which sediment treatment can be achieved. If treatment amendments are being applied at the water surface and are allowed to settle by gravity to the bottom of the water column (for example, using Aquagate and SediMite), then the total water depth and the water velocity determine how far downstream the amendments travel before settling onto the sediment. If the water depth is so great that amendments must be placed at a significant distance from the area where treatment is required, then the reliability of treatment may be lower. Bathymetry data are also needed because irregular sediment surfaces may cause challenges for mechanical delivery systems.

Modeling alone may not be sufficient to predict amendment transport well enough to design the delivery system to target the treatment area. Therefore, the water depth data is required not only in the exact location where treatment is required, but also along the river channel upstream. *In all cases the delivery mechanism must be able to deliver amendments to the targeted sediment areas.* Accurate delivery and placement methods continue to improve, thus expanding potential application of in situ treatment to a wider range of aquatic environments.

4.4.1.10 Erosional Potential

Erosion data is needed because erosional potential is directly related to sediment stability. *In general, surface-applied or thin-layer in situ treatment amendments (passively mixed) are not well suited to high energy environments. It is difficult to place amendments in areas with large erosion or scour potential because erosion may expose deeper contaminated sediments or may cause an amendment to erode before it can be naturally mixed in to the sediment.*

Conversely, in situ solidification/stabilization of sediment, which is achieved through active injection of amendments and mechanical mixing, reduces erosional potential. In this case, the erosion potential of existing sediments is relatively unimportant.

4.4.2 Sediment Characteristics

Data regarding characteristics of the sediment bed help to define the geotechnical properties necessary to support the application and mixing of an in situ treatment amendment. While the size, sorting, and orientation of the physical grains provide sediment stability, the benthic community contributes mixing of the contaminants as well as natural mixing of amendments. During the application of the amendment, the ability of the sediment bed to support the amendment prior to mixing can result in temporary release of contaminants due to surface pressure or can allow a slight penetration of amendment into the sediment bed due to density differences.

4.4.2.1 Particle (Grain) Size Distribution

Data regarding sediment particle size and distribution is necessary because in situ treatment tends to be most appropriate for fine-grained depositional sediments. Particle size distribution also affects sediment properties such as the depth of the BAZ, stratification (layers of coarse and fine sediment), and adsorption. Methods for measuring particle size include the sieve with hydrometer method (ASTM D422) and sand-silt-clay content by pipette (PSEP) method.

Particle size distribution in sediments affects various aspects of in situ treatment design. Significant differences in particle size or densities between amendment materials and sediment can cause problems with mixing, which can reduce the effectiveness of in situ treatment. Some studies have shown a direct relationship between particle size and reaction rates when treating sediment, although the mechanism is not well understood. Additionally, the percentage of silt and clay particles present in bottom sediments determines the composition of the biological community, the adsorption of contaminants to sediment particles, and the exposure of organisms to contaminants. The biological community and exposure are relevant for in situ treatment because the sediments will not be removed or covered, so the biological community is expected to remain in direct contact with the sediment after treatment. The adsorption of contaminants (and potentially treatment amendments as well) can be influenced by the specific grain size distribution. Clays, for example, have a permanent negative surface charge and often provide a sorption surface (and mechanism) for metal anions (positively charged ions).

4.4.2.2 Geotechnical Parameters

The efficacy of in situ treatment increases with increasing sediment stability, cohesiveness, shear strength, and bulk density. Data regarding these geotechnical test parameters help to define sediment stability and the fate of sediment and amendments that are added. These factors also determine the potential for resuspension and release of sediments and contaminants. *If sediments are stable with high shear strength and cohesiveness, then amendments that are added are likely to stay in place long enough to be effective, especially for many promising applications that do not involve mechanical mixing of amendments into the sediment. On the other hand, the method of amendment addition can cause changes in the stability conditions. Mechanical mixing with sediment, for example, can reduce cohesiveness and bulk density in a way that reduces shear strength and stability (with the possible exception of stabilization/solidification, which would actually increase shear strength and stability after treatment).*

The presence of a nepheloid layer sediment zone makes mechanical treatment, capping, or removal processes difficult because any disturbance of the zone can potentially cause the sediment to simply move rather than be treated or removed. Even placement of sediment capping materials can cause the nepheloid materials to be pushed aside into neighboring areas. Relatively light (low density) in situ treatment amendments can be applied from the surface and, on passing through the nepheloid layer, could mix with suspended sediments to achieve some treatment. Nepheloid layer data can help to determine whether this layer is driving risk levels at the site and whether treatment may be effective in this zone.

4.4.2.3 Pore-water Expression

Most in situ treatments apply a thin layer of amendments that adds little additional pressure on sediments. Pore-water expression, however, may be a factor if greater amounts of in situ treatment amendments are applied to the sediment bed. The influence of this pore-water generation on the effectiveness of the in situ treatment amendment depends on the treatment method and site conditions. In general, treatment amendments are applied at a rate of about 1 to 5% by mass of the sediments being treated, so pore-water expression is unlikely. Any expressed pore water that is generated would additionally pass through the treatment amendment materials, thereby being attenuated in the process.

4.4.2.4 Potential for Resuspension, Release, and Residual During Implementation

Data and modeling that provides insight on potential for resuspension under a range of foreseeable conditions are valuable for judging whether in situ treatment will be effective. The potential for resuspension from in situ sediment treatment depends on the type of treatment technology being used. Mechanical mixing, for example, can cause resuspension of sediments and release of contaminants into the water column (similar to, but more limited than, resuspension from dredging). The degree and speed of mixing controls the magnitude of resuspension and release. Because sediments are not lifted up through the water column, the resuspension and release are less extensive than that from dredging, but may be greater than that from capping. For sediment treatment that places amendments by gravity-settlement through the water column, resuspension and release are expected to be minimal because only a small amount of material is placed and the density of the materials is similar to the existing sediment. Resuspension data can also be used when in situ treatment is evaluated for treating the resuspended contamination from dredging (see Section 6.3.5.2).

Residual contaminated sediments can be generated by in situ treatment if resuspension occurs as described above. Treating sediment from upstream to downstream minimizes generated residuals. Subsequent treatment applications also capture a portion of the generated residuals from upstream. In situ treatment can also leave untreated sediment residuals if the amendment application is not fully effective (for example, if the mixing mechanism cannot reach into corners or cannot achieve the required depth).

4.4.2.5 Benthic Community Structure and Bioturbation Potential

Data regarding the benthic community structure is relevant because the benthic community determines the bioturbation potential, the BAZ, and the type of acceptable final substrates (if a remedial goal is to achieve a particular community structure or to maintain the current structure). *The presence of a healthy, high-quality community may support the selection of low-impact treatment that does not destroy the existing habitat and community. Where surface application of an amendment is used, the benthic community should include worms and other organisms that provide bioturbation (on the order of 5–15 cm is typically sufficient), which will provide natural mixing of amendments into the sediment.*

Certain types of treatment amendments rely on the activity of the benthic community to provide adequate mixing. Current in situ treatments using AC often rely on gravity settling through the water column and mixing of the carbon into the surface sediment by bioturbation. If this treatment approach is used, adequate bioturbation potential must be available to achieve mixing; a depth on the order of 5–15 cm is generally sufficient to reduce the bioaccumulation of PCBs, for example. Bioturbation depth information can be obtained from chemical and radioisotope profile cores and from vertical profiling cameras, sometimes referred to as sediment profile imaging (SPI). Bioturbation rate information typically requires radioisotope analyses (such as beryllium-7).

Additional factors affect the benthic community. For example, the potential toxicity of the treatment amendment should be considered for the specific benthic community present. Amendment toxicity can affect the quantity of material that can be safely used (application rate or dosage), as well as the method of placement. The depth of the BAZ is another critical factor. SPI cameras can be used to determine the depth of the BAZ to help achieve treatment throughout the entire BAZ.

In situ treatment can change the physical characteristics of the sediment surface, which can also affect the benthic community. Mechanical mixing of sediment, for example, may make the substrate looser, which can increase the potential penetration depth for benthic organisms. On the other hand, a soft sediment surface may be converted into a hard substrate if solidification is used. The types of benthic organisms that can use the new substrate may be different from those that were present before treatment, or the depth of bioturbation (the BAZ) may be changed. Finally, the relative recovery rate of the community structure should be evaluated and estimated. This value may help to determine the relative applicability or desirability of various treatment materials and methods. Several field implementation projects have shown that adding up to 4% (by weight) AC to sediment, by gravity settlement and passive mixing into the surficial (bioactive) layer, does not cause unacceptable adverse effects to the benthic community.

4.4.3 Contaminant Characteristics

Characteristics of the contaminants are particularly valuable in assessing in situ treatment. Contaminants must either be able to be absorbed on amendments such as AC or be degradable. The contaminants must be accessible with current amendment application and distribution systems and distributed in concentrations that can be treated. Mobility of the contaminant may contribute to exposure and may require an amendment to reduce mobility. Contaminant mobility may be increased unintentionally by the addition of an amendment. In either case, the assessment of contaminant species determines the most effective in situ treatment.

4.4.3.1 Contaminant Type - Forensics/Speciation

Data regarding contaminant type determines whether treatment is possible and what type of treatment can be used. For example, in situ treatment should be considered for sites where hydrophobic organic contaminants (such as PCBs) or methylmercury are the primary COCs because enough experience with in situ treatment using AC and other amendments is available for these contaminant classes to warrant consideration. When these chemicals are the risk drivers, in situ treatment can be a promising low-impact alternative. In situ degradation of hydrocarbons has also been demonstrated by injecting oxidants and in situ solidification/stabilization has been used to some extent for a variety of contaminant types including metals and hydrocarbons. In situ treatment experience is not as extensive for other contaminants and if these contaminants are the risk drivers, then literature searches and an extensive laboratory testing program are needed to assess whether in situ treatment is viable.

If the primary risk driver is a metal, then the metal speciation may be important if the treatment contemplated is only effective on one form or species of the contaminant. An example of a contaminant that exists in various forms is arsenic, which may be present as inorganic arsenate (AsV), inorganic arsenite (AsIII), methylated arsenic, or organoarsenic. Speciation data in this situation can help to determine contaminant mobility, toxicity, and treatment potential.

4.4.3.2 Vertical and Horizontal Distribution of Contamination

Because most in situ treatment technologies target surface sediments, information on the vertical distribution of contamination is key to treatment design. *In situ treatment may be preferred at sites where concentrations are higher in deeper sediments and within zones where surficial contaminant concentrations are fairly uniform. If the entire depth of contamination is to be treated, then the depth must be within the practical implementation limits of the in situ treatment technology selected.* When required treatment depths exceed several feet, in situ treatment may become difficult to implement. An exception is in situ stabilization/solidification (ISS), which has been performed at greater depths. ISS is an aggressive treatment technology that may involve installing a sheet pile wall or cofferdam, removal of overlying surface water, and mechanical mixing of amendments with augers or other devices to reach greater treatment depths.

Surface applications of in situ treatment amendments are unlikely to have significant effect on deeper sediments. It may not be necessary, however, to treat deeper contamination if the sediment is considered stable or the area is a depositional environment. If it is necessary to treat deeper contamination, consider whether the available in situ treatment technologies can penetrate to the necessary sediment depth. If the highest concentrations are below the surface, then clean sediment is most likely depositing on the surface and mixing with the bed sediments, thus naturally reducing exposure concentrations. Note that high concentrations at depth can potentially migrate to the surface, either by groundwater advection, diffusion through pore water, biological activity, or other mechanical processes such as gas ebullition. If deeper contamination has the potential to essentially recontaminate surface sediment, then the contaminant flux must be quantitatively assessed and treatment adjusted to accommodate the additional contaminant load.

The horizontal distribution of contaminants also informs design choices. While a large lateral area may be affected, that area may contain certain hot spots with elevated concentrations surrounded by areas with lower concentrations of contaminants. In these cases, it may not be necessary to use in situ treatment across the entire area if exposure to the target receptors is primarily from higher contaminant concentration areas. Similarly, the concentrations within the hot spot zones may be too high to be treated effectively by the available in situ technologies. An effective remedy for these areas may involve a combination of removal of the hot spots, followed by in situ treatment of the less contaminated areas.

4.4.3.3 Contaminant Concentrations

The dose of an in situ treatment amendment needed to reduce risks to acceptable levels is typically proportional to the contaminant concentration. As contaminant concentrations increase, the dosage required also increases up to a certain level, above which it is no longer feasible to consider in situ treatment with amendments. For example, if AC is to be added to the sediment, but calculations or bench-scale tests indicate that carbon must be added at a dosage of 20% of the sediment mass to be treated, then this additional mass would lead to significant alterations of the sediment substrate itself and may cause unacceptable damage to the habitat. The increase in concentration may also require such a high dose (or multiple doses) of amendments that the treatment would be cost prohibitive. Upper bounds on contaminant concentrations are site-specific determinations based on site-specific risk estimates and risk management goals. Bench-scale and in situ treatability and pilot testing may be required to determine whether risks can be adequately reduced using in situ treatment.

Contaminant concentrations are less relevant when ISS is used. An upper bound on the concentrations that can be treated may exist, but because ISS is a predominantly physical process that affects the sediment matrix, the limitation on concentrations may not be as significant as it is for other in situ treatment techniques (see Section 4.4.3.2).

4.4.3.4 Contaminant Mobility

If the goal of treatment is to reduce contaminant mobility, then data about the specific conditions affecting mobility are needed in order to select an appropriate treatment. Conversely, if the treatment itself could increase contaminant mobility, the impact on site risks must be evaluated prior to selecting this technology. *In general, treatment is likely to be most effective for contaminants that are not highly mobile or that will not be mobilized by the treatment itself.*

4.4.3.5 Bioavailability

Most in situ remedies treat contaminants that are bioavailable because these contaminants are the primary source of risk potential. *Information on the bioavailability of the chemicals is a useful design parameter and site-specific bench-scale tests should be used to confirm that bioavailability will be reduced by the selected in situ treatment method.*

In some cases, reliance on existing experience and literature may be sufficient to confirm that treatment would be effective at reducing bioavailability. Risk reduction with respect to bioavailability is pathway specific. Thus, while treatment typically works on freely dissolved chemicals, exposures involving pathways such as incidental ingestion of sediment by humans might not be adequately reduced by in situ treatments.

4.4.3.6 Bioaccumulation/Biomagnification Potential

The predominant current approach to in situ treatment uses AC to bind hydrophobic chemicals, such as PCBs, that bioaccumulate and biomagnify in food webs. Thus, for bioaccumulative chemicals that can be treated by a sorbent, in situ treatment with AC offers a viable option for reducing exposures. For bioaccumulative compounds, an adequate reduction in exposure (either through sequestration, reductions in bioavailability, or through destruction/transformation of contaminants) must occur in order to meet site-specific remedial objectives. Because exposure areas for higher trophic levels may be different from the exposure areas under consideration for in situ treatment, the degree of treatment is not necessarily correlated with reduction in the tissue concentrations of chemicals, especially when uncontrolled sources of these chemicals are present.

4.4.3.7 Transformation or Degradation Potential (Biotic and Abiotic)

The transformation or degradation potential (both biotic and abiotic) is essential information to gather before evaluating in situ treatment if the intent of treatment is to transform or degrade the contaminants. The specific biotic and abiotic pathways by which the contaminant degrades or is transformed is used to select an appropriate treatment amendment. Contaminants that have high potential for transformation or degradation to nontoxic forms are amenable to in situ treatment.

4.4.3.8 Nonaqueous Phase Liquids (Presence of Source Material)

The presence of nonaqueous phase liquids (NAPLs), such as petroleum products or chlorinated solvents, in sediment can be a potential problem for some in situ treatment technologies. For example, if AC becomes saturated with NAPL, then the treatment becomes less effective in controlling dissolved constituents. Other amendments, however, such as organo-clay can be used to achieve treatment where NAPLs are present. In general, it is difficult to treat all NAPLs in situ because of mass-transfer limitations (slow dissolution and reaction of free product). Therefore, NAPL can continue to act as a source of contamination long after treatment amendments are applied, especially if groundwater flux, diffusion, or gas ebullition cause upward movement of deeper NAPL. The nature and extent of any NAPL that may be present should be incorporated into the evaluation of effectiveness of in situ treatment. The estimated contaminant flux from the NAPL should be less than the long-term treatment capacity of the treatment amendments applied.

4.4.3.9 Source Identification and Control

Sources of contamination in the system must be identified and controlled prior to implementing in situ treatment (see Section 2.3). Potential continuing sources can result from groundwater flux, stormwater and process water outfalls, and nonpoint sources such as runoff and atmospheric deposition. If ongoing sources are well defined and predictable, it may be possible to provide for future treatment by increasing the initial dose of treatment amendments.

4.4.3.10 Ebullition

Ebullition, the migration and release of gases from sediment, may enhance transport and provide preferential pathways for groundwater and NAPL transport of contaminants from depth into or through the in situ treatment zone. Ebullition can also disturb the vertical stratification of sediment contaminants or the stability of sediments, thus preventing adequate contact between contaminants and treatment amendments and resulting in reduced treatment effectiveness. Ebullition is of particular significance for solidification because it can adversely affect the integrity of the solid matrix formed.

In addition, if ebullition causes upward movement of buried contamination, then the treatment amendment dosage and anticipated long-term effectiveness are affected. As with other sediment processes, it is important to determine the quantitative extent and magnitude of ebullition and how the additional flux resulting from that process may affect the remedy (see USEPA 2013a).

4.4.3.11 Background Concentrations

Background concentrations indicate the contaminant concentrations of material that will deposit on the sediment bed over time. Background concentrations should be taken into account during the design of application estimates for in situ treatment material (see Section 2.2).

4.4.3.12 Exposure Pathways

In situ treatments work best for controlling exposure pathways to the aquatic food web that involve direct or indirect exposure to the available chemicals in the sediments. These pathways could include a direct exposure resulting in toxicity to biota, bioaccumulation into benthic invertebrates with potential transfer to higher trophic levels (including wildlife and humans), and flux to the overlying water column with subsequent exposures to water column biota (algae, zooplankton, and fish). Therefore, a CSM that includes these pathways can help target where in situ treatment may be most appropriate. The effectiveness of in situ treatment in situations where a high likelihood for direct sediment contact or incidental sediment ingestion by humans exists is less well understood and would require a consideration of how such exposures are influenced by the bioavailability of the chemicals (either incidentally ingested or that come into contact with the skin).

4.4.4 Land and Water Use Characteristics Data Needs

Current and future use of the land above and adjacent to the waterway, and the waterway itself, may be limited due to the resources that require protection such as cultural resources, critical habitat, and sensitive species. These concerns are sometimes balanced by the anticipated use of the waterway during implementation and after remediation. In situ treatment, like all other treatments, is susceptible to recontamination from sources that are unrelated to the site but continue to contribute contaminants to the site. Understanding these additional contaminant contributions is essential before selecting in situ treatment or designing the treatment.

4.4.4.1 Watershed Sources and Impacts

As with any sediment remedy, the presence of ongoing sources also affects the potential efficacy of in situ treatment technologies. Watershed characteristics also influence sediment loading and deposition, potential for flashiness and erosive events, and the biological productivity of the system. The biological productivity of the system is affected by agricultural runoff (nutrients such as phosphorous and nitrogen) and wastewater overflow or posttreatment releases (such as biological oxygen demand or nutrients).

Watershed inputs can enhance or reduce treatment effectiveness. For example, if nutrients and organic carbon are being added to the system and are necessary for treatment reactions such as bioremediation to occur, then the watershed effects can increase treatment effectiveness. On the other hand, if the added constituents change the biochemistry of the sediment environment in a way that impedes treatment, adverse effects on treatment occur. *In general, for in situ treatment* *to be effective, the ongoing sources of both target contaminants and other constituents must be anticipated and the information must be used in design of the in situ treatment.*

4.4.4.2 Cultural and Archeological Resources

Because of their low-impact nature, in situ treatment technologies should not pose a significant threat to cultural and archeological resources, unless the treatment will be implemented using aggressive mechanical mixing of sediment. Nevertheless, determining the nature of cultural or archeological resources in the contaminated area is important for any remedial technology and should be communicated to all interested parties. In situations where cultural or archeological resources have been identified, in situ treatment may be a preferred remedial alternative for reducing exposures. For example, if AC is added at the surface, sinks to the sediment surface, and is passively mixed in by benthic organisms (a typical in situ treatment approach), cultural or archeological resources are not disturbed.

4.4.4.3 Site Accessibility

A safe, efficient means to deliver and place treatment amendments is required to successfully implement this technology. Some of the considerations for evaluating site accessibility include:

- Will treatment be performed over the water or from the shore?
- Is an adequate base treatment area available on shore to stage equipment?
- If amendments will be placed, is a boat launch convenient, from which amendments can be cost-effectively transported to the target area? If the distance is more than 5 or 10 miles, then cost estimates must confirm that treatment will be cost effective.

4.4.4.4 Current and Anticipated Waterway Use

Current and anticipated waterway uses can affect both the implementation of in situ treatment and the long-term effectiveness of treatment. *The disruption of sediment during treatment should be minimized and the treatment itself should not interfere with current or reasonably anticipated future uses (or use can be postponed during treatment).*

Placement of a thin layer of material, a common form of in situ treatment, may not interfere with waterway use even in navigation channels; however, the current and anticipated waterway uses must be considered on a site-by-site basis. Consider the following when evaluating waterway use:

- Navigational and recreational use can hamper implementation.
- Boat traffic erosive effects (such as prop wash, particularly in the near-shore environment if only small recreational vessels are present), future dredging to maintain channel depth, and waterfront construction projects can all cause deeper contamination to become exposed or the treatment layer to be disturbed, potentially releasing contaminants (not an issue if treatment is fast, complete, and irreversible).

- Potential for exposure to treatment amendments by people swimming or fishing should be considered in recreational areas.
- Quality of life for waterfront residents during implementation may be impaired due to increased boat traffic, temporary area use restrictions, and other project requirements.

4.4.4.5 Current and Anticipated Land Use

In situ treatment has relatively little effect on land use because once the treatment has been performed, little need exists to retain structures or other operations on land. The primary concerns with current land use are accessibility and the potential for re-treatment if long term monitoring indicates that treatment effectiveness has been reduced.

4.4.4.6 Unique or Sensitive Species

In situ treatments that are low-impact may be more appropriate when unique or sensitive species are present than more invasive remedies. Data on these species are particularly relevant for determining whether the site is appropriate for a low-impact treatment remedy. While most of the current in situ remedies tend to be low-impact, some in situ treatment methods (such as solidification) could transform the habitat or directly injure stationary organisms such as mussels. Potential negative effects of the amendments on the species present must be considered in selecting the type and dose of treatment amendment. Bench-scale or pilot testing may be required to estimate potential effects on these species and to evaluate if the effects are short term or potentially long term. A wide range of field-scale pilot studies have shown that potential effects of AC amendments on the ecological community are limited, particularly at AC doses of less than roughly 4% (Patmont et al. 2013). At many contaminated sediment sites, the positive effects of AC reducing toxicity generally outweigh the potential negative ecological effects of AC, and therefore lead to substantial improvement of habitat quality (Kupryianchyk et al. 2012).

4.5 Evaluation Process

The sections below provide some of the information necessary to evaluate in situ treatment and compare it to other alternatives. Before selecting in situ treatment as a final remedy, one or more of the following types of studies will likely be required and may be necessary during remedial design or prior to the start of construction.

1. *Literature review*. Demonstrate through literature review and calculations that the proposed treatment approach can be effective at reducing the risks at the site. If sufficient literature documentation is available to support the use of in situ treatment, then the following two steps may not be needed.
2. *Bench-scale (laboratory) treatability studies*. If the literature review suggests that in situ treatment may be possible, then bench-scale (laboratory) treatability testing using a variety of mixtures and doses of amendments can be implemented. If the literature review indicates that in situ treatment is possible, but not well documented, then the bench-scale testing would likely be conducted as part of the remedy selection process (perhaps during preparation of a

feasibility study). On the other hand, if sufficient evidence indicates that in situ treatment is effective, then the bench scale testing may be performed after remedy selection to determine the appropriate amendments and doses for delivery.

3. *Field pilot studies*. If a new or innovative delivery system is to be used or if there are unique site conditions that could affect implementation, then pilot studies using one or more methods of amendment delivery are appropriate. Pilot studies may be needed as part of the remedy selection if significant uncertainty exists regarding the ability to deliver amendments to sediments in situ, or if there are concerns regarding site-specific treatment effectiveness (for example, significant heterogeneity is present). It is more common, however, for pilot studies to be performed as part of remedial design or just prior to implementation to confirm and refine the methods used. Pilot-scale tests help establish which delivery mechanism will be most effective, and whether treatment of the site sediments can provide the targeted reductions of risks. Note that AC placement has now been demonstrated using a wide range of conventional equipment and delivery systems; uniform AC placement has also been demonstrated in relatively deep and moving water (Patmont et al. 2013). Therefore, field pilot studies for AC placement should not be needed prior to selecting this technology as part of the remedy.

4.5.1 Protection of Human Health and the Environment

Protection of human health and the environment is typically considered a threshold criterion for any remedial alternative. In situ treatment approaches must adequately meet this criterion to be considered. The design process should determine whether in situ treatment technologies are likely to reduce current and future risks to levels consistent with remedial objectives for the site. This assessment is generally based on either a reduction in mobility or availability of contaminants, or actual degradation of the contaminants. The assessment of whether a treatment technology can meet remedial goals related to human health is typically based on literature and site-specific bench-scale or pilot tests.

4.5.2 Short-term Effects

The acceptability of an in situ remedy depends in part on the potential short-term adverse effects from implementation of the remedy. Other issues related to recovery rates are also important considerations. Some of the relevant issues include:

- *Effects on habitat and resident biota*. Although in situ treatment approaches are generally considered to have far fewer negative effects on habitat or the existing benthic community, some in situ technologies, such as AC amendment, may have less potential impact than others (in situ mechanical mixing, solidification). In addition, the potential effects of specific amendments should be considered with regard to growth and diversity, relative to other remedial alternatives. For example, Beckingham, Vanderwalker, and Ghosh (2013) identified an effect on plant growth after amendment with 5% AC or greater, possibly due to changes in the sediment structure or availability of nutrients, and Millward et al. (2005) identified a possible effect on polychaete growth after amendment of the sediment with AC. In this case, monitored natural recovery would likely be considered the only remedial alternative that would be less damaging or harmful to habitat or benthic communities from the implementation itself. The cumulative effects from exposure to contaminants also must be considered.

- *Release, resuspension, and untreated residuals (RR&R)*. The extent of RR&R for in situ treatment depends on the amendment, objective, and delivery system and may range from minimal effects, to effects comparable to dredging. For example, placement of AC on the sediment surface by gravity-driven settlement should cause very little RR&R; however, using augers to mix amendments into deep sediments could cause significant RR&R. The extent to which the delivery mechanism disturbs in-place sediment dictates the extent of RR&R. Controls similar to those used during dredging can be used to reduce RR&R. For example, mixing sediments with amendments inside steel caissons has been shown to mitigate the RR&R potential. RR&R should be examined for all sediment remediation alternatives and evaluated under a similar framework.
- *Community effects*. Potential effects of any remedial technology on the surrounding community during and after implementation must be considered. For example, although in situ treatment may cause less traffic than capping or dredging, some level of truck traffic is associated with implementation of this technology. Therefore, increased traffic through residential neighborhoods, potential wear and tear on roadways, noise, and other effects should be considered when evaluating this technology.
- *Resource consumption and sustainability (sustainability evaluation)*. The resources consumed include resources to manufacture, transport, and deliver amendments to the sediment. Use of AC made from renewable raw materials such as coconut shell or other biomass waste products can lead to long-term sequestration of recently captured carbon and may provide a lower carbon footprint of the remedy compared to other energy intensive remedial options.
- *Time to achieve protection*. The time required to achieve adequate protection depends on the time needed to design and implement the technology, the speed of implementation of the remedy, and the time to reach the point at which adequate contact between the contaminants and amendment material to provide the target reductions has been achieved. The potential implications of other factors such as recontamination from incompletely treated sediment or an interceding storm event should also be considered in evaluating the time required to achieve protection.

4.5.3 Long-term Effectiveness

The acceptability of an in situ remedy also depends on how well the remedy performs over the long term. Some considerations for long-term effectiveness include:

- *Potential for chemical releases from treatment zone*. The potential for future events to lead to the release of contaminants from the amendment materials should be evaluated. This potential is negligible for chemicals that have been degraded or sequestered. Future releases may be possible, however, for contaminants that have not been treated (due to poor implementation or by design, when only surficial sediments are treated) and where new and untreated chemicals have been introduced to the treatment zone after the treatment was implemented. In general, most in situ treatments are permanent, even those that rely on sequestration; however, sorption of certain metals can be reversed in the presence of other metals (due to cation exchange) or change in pH and redox conditions. No in situ treatment projects have been monitored for long periods of time (30 to 50 years), so some uncertainty exists regarding the reversibility of sequestration using AC. If in situ treatment results in complete destruction of contaminants, however, then no future releases of these contaminants can occur.

- *Depth*. The depth of contamination may affect long-term effectiveness if the treatment amendments cannot penetrate to the maximum contaminant depth or contamination at depth is considered an ongoing source. For example, placement of amendments on the sediment surface results in a mixing zone limited to the bioturbation zone, which would be on the order of several inches. On the other hand, using augers inside caissons achieves much higher maximum mixing depths. The extent to which treatment depth is important depends on a range of factors, including sediment stability, upwelling of groundwater, and relative mobility of contamination at depth.
- *Capacity*. An inherent limitation of most in situ treatment approaches is that the amendment materials have some finite capacity to convert, bind, or otherwise immobilize contaminants. Long-term effectiveness can be reduced if the quantity of contamination exceeds the capacity of the amendment materials. This problem primarily occurs in areas where a flux of untreated chemicals enters the treatment zone because of resuspension from other areas or the presence of ongoing contaminant sources. If treatment has been designed properly, treatment capacity required for the target inventory of chemicals should be known. The introduction of untreated chemicals to the treatment zone following treatment can occur from site-related issues (such as upwelling and movement of contamination from one area to another). Additional untreated chemicals can also result from design-related issues such as insufficient thickness or capacity of the amendment at a particular location or movement of the amendments.
- *Recontamination*. Recontamination of a treated area with new and untreated chemicals can give the appearance that the treatment efficacy is diminishing or reversing. Treatment amendments may continue to provide protection, however, if added at concentrations sufficient to provide capacity to treat recontamination from uncontrolled sources. From this perspective, in situ treatment has the potential to provide better long-term protectiveness from recontamination than dredging or capping.

4.5.4 Implementability

Implementability of in situ treatment depends on the following factors:

- *Access for equipment*. In situ treatment is often selected to protect areas with high-value habitat, which can be remote and difficult to access. Generally, in situ treatment methods require less material and equipment than capping or dredging, and thus present fewer access issues. In addition, in situ treatments that use sprayed treatment material (such as SediMite and AquaGate) allow treatment of otherwise inaccessible places. Other in situ technologies, such as mixing and augering, may require significantly more equipment, for which access becomes an issue.

- *Amendment availability*. Some amendment materials (such as AC) are readily available in large quantities, while other materials are either experimental or are not produced at sufficient quantities for use at large project sites. During treatment evaluation and laboratory treatability testing, a supply source for any potential amendments should be identified and both availability and cost of materials confirmed before moving forward with additional testing or final design.
- *Delivery system*. Implementation of an in situ treatment remedy often depends on the delivery system. The wide range of amendment materials available all have different physical properties (particle size, bulk density, and handling characteristics), which can affect the choice of delivery method. Examples of commercial delivery systems available include SediMite and AquaGate (amended AquaBlok). Some amendment materials do not require a special delivery system, other than a device for spreading or mixing the amendment. When in situ treatment amendments are selected for either bench-scale or laboratory testing, effective placement of these materials with an appropriate delivery system should also be evaluated.

4.5.5 Cost

The total cost for in situ treatment can vary widely depending on amendment quantity and cost, delivery system cost, and the cost of placement and implementation (including monitoring and verification). It is often not possible to determine amendment quantities until preliminary laboratory treatability studies have been performed and objectives for contaminant reductions are determined. The primary factors that drive in situ treatment costs include:

- *Amendment materials*. The amendment type and quantity of amendment required is a significant cost driver. Many amendment materials can cost a dollar to several dollars per pound. Given the high cost of these amendments, uniform distribution over large surface areas becomes a key consideration. A delivery system that can uniformly apply even small quantities of amendments is critical for cost control. In order to provide a reasonable estimate of costs for amendments, both the amendment raw material and the delivery system should be evaluated during design, from the treatability phase forward.
- *Implementation methods*. Implementation can be broken down into two key categories: placement of the amendments during installation and construction monitoring. The type of amendment selected affects the relative cost of installation. In some cases, the amendments can be placed without modification, but in other cases the use of a delivery system can reduce the cost of installation and provide superior uniformity and speed of placement. In estimating the cost of installation, evaluate both the amendment material and the delivery or placement method. For monitoring, the construction phase monitoring is often considered a

quality control activity (used to verify that initial treatment objectives were met) that is included in the installation costs. This item is separate from subsequent monitoring related to achieving the remedial design objectives.

- *Performance monitoring*. Post-remedial monitoring costs are also associated with in situ treatment (as with any remedy). These costs can vary depending on the treatment technologies selected and can be influenced by such factors as whether the monitoring is for freely dissolved, total bulk chemical concentrations or for tissue concentrations.

4.5.6 Reduction in Contaminant Toxicity, Mobility, or Volume through Treatment

In situ amendments target different types of contaminants in sediment and function through different mechanisms to reduce the availability or effects of contaminants in the environment. AC is widely used as a treatment amendment because it is proven to reduce mobility and bioavailability (and thus exposure to contaminants) through adsorption and immobilization. Additionally, organophilic clay, zeolites, and iron oxide/hydroxide can bind contaminants in the sediments through adsorption, thus reducing mobility and exposure to biota and humans. Other amendments designed to degrade the chemicals or transform them into less toxic forms (reduction in toxic contaminant volume) include apatite, biostimulation (ozone) and bioaugmentation amendments, and ZVI compounds. Additional amendments such as cement, with or without lime or fly ash, can physically solidify or stabilize contaminants (see Table 4-1).

4.5.7 ARARs

Few ARARs relate specifically to contaminant levels in sediments. ARARs that apply are typically associated with the overlying surface water and, for these, a relationship between flux of contaminants from sediments and surface water concentrations may exist. Thus, a surface water ARAR may result in a remedial objective for contaminants in sediments.

Other action- or location-specific ARARs, however, may apply for in situ sediment treatment. For example, a state may have restrictions regarding what materials can be added to a public waterway. Similarly, the U.S. Army Corp of Engineers (USACE) regulates navigable waterways, so certain permitting requirements may be triggered by in situ treatment. In general, in situ treatment is not likely to have more difficulty achieving ARARs than capping or dredging.

4.5.8 State Acceptance

Little experience is available regarding state acceptance of in situ treatment alternatives. Several states support using in situ treatment and no state is known to explicitly reject this technology. Additionally, many state cleanup statutes encourage treatment remedies over containment or removal technologies. Both states and communities are more likely to find in situ treatment a preferred option for minimizing environmental disturbance and reducing exposures.

4.5.9 Community and Stakeholder Involvement

In situ treatment, especially with sorbent/reactive amendments, is a relatively new approach for contaminated sediment management and presents some concerns for stakeholders, since contamination is left in place. Communities often favor removal as the preferred remedy for sediment remediation. This preference generally results from a lack of effective communication on alternatives that can reduce contaminants and risk with less disruption to the habitat and environment. In evaluating in situ treatment, recognize that an active program of outreach and education is necessary to inform the community and gain acceptance for a treatment that does not actively remove the contaminants. Discussions with stakeholders about remedy selection should include detailed analysis of application methods and the expected mode of risk reduction.

Engage stakeholders early. Unless stakeholders have an existing preference for minimally invasive remedial approaches, the evaluation of in situ treatment should include early discussions with key stakeholders to evaluate the level of acceptance for the approach. The support of key stakeholders has been proven to significantly influence both community and regulatory acceptance of in situ treatment approaches.

4.5.10 Other Applicable State or Tribal Requirements

No known applicable state or tribal requirements exist for in situ sediment treatment. Some tribes, however, may object to foreign materials being placed in the environment, especially in areas that the tribes consider sacred. See Chapter 8 for additional information on tribal stakeholder issues.

4.5.11 Green and Sustainable Technologies

In situ treatments offer several favorable and environmentally sustainable features, including: low energy costs, low emissions, low community disturbance, small footprints, and preservation of habitats. Additionally, ongoing work with biochars, such as AC, is promising and may offer a sustainable source of treatment amendments. These biochars can be produced from waste wood or other carbon sources including invasive species of plants such as *Phragmites* (common reeds). Biochar production for in situ treatment offers a waste disposal alternative, a means of managing invasive plants, and a method of carbon sequestration (through growth of the plants prior to harvesting). Finally, ITRC offers additional guidance on green and sustainable remediation approaches that may support in situ treatment (ITRC 2011b).

4.5.12 Habitat and Resource Restoration

A number of in situ treatment remedies are designed to have low environmental impact. These approaches can lower chemical exposures without compromising the habitat or species using the habitat. This low-impact footprint accelerates habitat and resource restoration and can potentially lower natural resource damages relative to other remedial alternatives.

4.5.13 Watershed Considerations

In situ remedies can be used in parts of the watershed where acceptable physical requirements are met. Treatment generally does not adversely affect the physical or hydrological characteristics of the watershed and is generally compatible with habitats and resources. Unless used as a temporary measure, in situ treatment is usually not applied to areas where deep contamination exists and where navigation or construction projects are planned.

4.6 Monitoring

Monitoring of stream and sediment conditions is essential to confirm that adequate amendment and distribution for treatment has been achieved. During the construction phase of an in situ treatment program, the sediment bed and associated contaminants may be resuspended during mixing and distributed downstream to an uncontaminated area. Similarly, valuable amendment may be lost or unevenly distributed along the sediment bed surface, depending on the hydrodynamics of the waterway, depth of water, delivery mechanism, and amendment used. During implementation, the stability of the sediment bed containing the amendment and the thickness of the treatment zone as well as the concentration of the amendment must be monitored to confirm that adequate treatment capacity exists (vertically and horizontally).

While construction monitoring confirms that the remedy has been properly implemented, monitoring of stream and sediment conditions after implementation evaluates the overall performance of the remedy. Performance monitoring results must be evaluated to determine whether the treatment has successfully reduced exposures to acceptable levels.

4.6.1 Construction and Implementation Monitoring

Constructions and implementation monitoring generally measures the relative success in achieving the designed delivery or placement of treatment agents to the sediments. The design goal is to establish contact, or near contact, between the treatment materials and the contaminants that are to be treated (in either the BAZ or a thicker sediment interval). For example, if site-specific bench-scale tests indicate that the desired amount of AC is 5% of the dry weight of the top 10 cm of sediment, then this value becomes the design basis for the application and the method of delivery. This design specification and any others developed for additional treatment agents become metrics for construction monitoring.

Treatment effectiveness is influenced by the degree of contact between the treatment agent and the contaminants and by the degree of horizontal and vertical mixing over the desired treatment area. Uneven distribution, loss of treatment agent in the water column, or poor mixing can reduce the effectiveness of the treatment. Construction and implementation monitoring measures the characteristics of the physical placement that can confirm delivery and mixing of treatment materials. These aspects of treatment performance are monitored by evaluating the horizontal and vertical distribution of treatment agent and the small-scale variability in treatment efficacy for reducing exposures.

Implementation of in situ treatment is similar to capping in several aspects that can affect monitoring (Palermo et al. 1998). For example, achieving distribution or placement of materials depends on the physical properties of the material being placed, the sediment on which it is being placed, and the flow characteristics and depth of the water body. These factors should be considered when developing a placement and construction monitoring plan. Evaluation can be performed through measurements such as thickness (immediately post placement through core samples or other means), composition (such as carbon content) of the completed installation, visual means (SPI camera), or a range of other physical or chemical methods (bathymetric, tray samples, or diver assist).

Variability and uncertainty often occur in placement and measurement approaches. Typically the thickness and composition should be specified on a statistical basis, such as 95% upper confidence limit on the mean or a reasonable tolerance to a target. Note that actual performance, as well as individual measurement methods, may vary from areal average values without a substantial impact on the overall performance of the treatment.

The construction and implementation monitoring for other in situ treatment approaches may vary substantially. For example, monitoring for in situ solidification may use chemical and physical targets (such as achieving final hydraulic conductivity values) that will limit the ultimate migration of contaminants contained within the solidified mass of treated sediment.

Construction and implementation monitoring methods for in situ treatment remedies are specific to the materials and techniques used. Because many of the materials and methods are relatively new or experimental, the design stage should include a careful selection of metrics to define success for construction and implementation.

4.6.2 Post-remediation Performance Monitoring

Performance monitoring for in situ treatment assesses treatment efficacy over time and monitors potential environmental effects from the treatment. While most in situ treatments are relatively low-impact, some in situ approaches have a greater effect on the surrounding area and must be monitored to confirm that the remedy does not cause harm to the environment.

The efficacy of most treatment technologies can be judged by how well they reduce short-term and long-term exposures. Most assessments of efficacy measure the degree to which concentrations of dissolved contaminant (C_{free}) are reduced in surficial sediments, but may also include demonstrating that contaminants are being transformed to nontoxic degradation products. Remedial goals are typically expressed as either a percent reduction in exposure over current levels or as specific target concentrations. Target concentrations are typically expressed as an average over the remediation zone, but in some situations might include single-point maximum allowable concentrations. In most cases, performance monitoring measures both bulk chemical concentrations in sediment and C_{free} either on a composite or point-by-point basis or as a composite over a set exposure level. For most full-scale in situ treatment projects, biological metrics may also be needed to provide assurance that the treatment is performing as expected. Performance monitoring can be adjusted as information is gathered over time and across the treatment area.

Some common performance monitoring methods include the following:

- Concentrations of available contaminants (C_{free}) is the most direct means for assessing performance of in situ treatment technologies that involve sorption processes. This value can be obtained by direct measures of this fraction or by other exposure metrics reflecting the available contaminants (ITRC 2011a). Monitoring can include pore-water measurements using passive sampling devices, the collection of biota in the field, or benthic invertebrate testing (either in situ or ex-situ) to judge toxicity or bioaccumulation. For persistent hydrophobic chemicals such as PCBs, treatment efficacy can usually be judged over a short period of time (months to years). For example, in situ treatment of PCBs with AC appears to occur very quickly, with large reductions in exposure occurring in a few months. Long-term performance monitoring, however, can be affected by introduction of additional contamination in the future (for example, if sources are not controlled prior to implementation). If long-term performance of in situ treatment appears to decline over time, monitoring for additional flux of contaminants into the waterway can indicate outside sources of contamination.
- Mass reduction is a performance metric used only for in situ technologies that degrade or destroy contaminants (such as biodegradation, abiotic reductive dechlorination, or chemical oxidation). For these techniques, samples can be collected after treatment and analyzed for the contaminants to determine whether concentrations have declined. Because sediments can move, the contaminant mass within a given treatment zone should be estimated both before and after treatment by an appropriate sampling program to determine whether the total mass of contaminant has been reduced by the treatment.
- Biological activity is a useful metric for in situ technologies based on bioremediation processes. Performance for these technologies is influenced by the activity of microorganisms responsible for the metabolism of the contaminants and the availability of adequate nutrients. Biological activity can be estimated by collecting samples and testing for the presence of certain species and by quantifying the number of organisms present (more organisms indicates higher activity). For some contaminants, intermediate degradation products or final metabolites can be detected, so measurement of these products/metabolites provides performance indicators of biological activity as well.
- Degradation byproducts can be measured to assess the performance of treatment technologies that provide for degradation of contaminants. For example, if reductive dechlorination of trichloroethene (TCE) is performed, then degradation byproducts such as dichloroethenes, ethene, and chloride ion can be investigated. Concentrations of these constituents should increase as the TCE concentration decreases.
- Food web exposure reduction is a valuable metric for treatment technologies that provide only for reductions in the bioavailable fraction of contaminants. Exposure can be monitored for bioaccumulative compounds by collecting and analyzing samples of biota in species that are known to accumulate contaminants in their tissues and that serve as food sources for higher trophic levels in the food web. Concentrations of contaminants should decrease after

treatment, which indicates a reduction in exposure. Long-term monitoring of fish tissue concentrations of contaminants is often a component of performance monitoring because the greatest risk associated with contaminated sediments is often the presence of contaminants in fish and the ingestion of those fish by humans and wildlife.

At some sites, differences between real and perceived changes in performance may be evident. It is possible to have effective treatment, but still observe an apparent decrease in treatment efficacy over time. For example, if a previously unknown source is releasing contaminants into the system, fish tissue concentrations may stop decreasing or begin increasing again in the future. Higher fish tissue concentrations could lead to a perception that the treatment is no longer effective. The real versus perceived performance of an in situ treatment alternative is affected by the following factors:

- how well the treatment agent binds or breaks down the chemicals of interest and if the process is reversible
- how well the treatment agent is mixed with the sediment and with the chemicals of interest
- resuspension and transport of sediment
- presence of areas and sources that can recontaminate the sediments

If performance appears to decline over time (or if treatment appears to be reversed in the long-term), then post-implementation monitoring may also include additional sampling or testing to determine the cause of the poor performance.

4.7 Case Studies for In situ Treatment

Table 4-3. Case studies describing in situ treatment

Pilot Study	Contaminant and Amendment	Site Description	Application	Reference
Hunters Point, San Francisco Bay, CA, 2004 and 2006	PCB/AC	Tidal Mud Flat	1. Slurry injection 2. Tiller	Cho et al. 2007 Cho et al. 2009
Grasse River, NY 2006	PCB/Granulated AC	River	Tiller	Beckingham and Ghosh 2011
Trondheim Harbor, Norway, 2007	PAHs, PCB/Powdered AC and AC-bentonite	Harbor	Slurry application	Norwegian Research Council 2011
James River, VA	Hydrophobic contaminants/ AC	Estuarine Wetland	SediMite	Menzie 2012
Deep Fjord, Grenlandfjords, Norway, 2009	PCDD/F/AC mixed with clays	Fjord	Thin-layer cap	Cornelissen et al. 2012

5.0 CONVENTIONAL AND AMENDED CAPPING

Capping is the process of placing a clean layer of sand, sediments or other material over contaminated sediments in order to mitigate risk posed by those sediments. The cap may also include geotextiles to aid in layer separation or geotechnical stability, amendments to enhance protectiveness, or additional layers to armor and maintain its integrity or enhance its habitat characteristics.

When amendments are mixed directly into sediments, the resulting remedy is termed "in situ treatment" (Chapter 4). When these amendments are added to cap material, the remedy is called an "amended cap," and the amendments enhance the performance of the cap material. The same amendment used in the same proportions is generally more effective at isolating contaminants when used in a cap than when placed directly into sediments. The amended cap provides the benefits of capping in addition to the benefits of the treatment amendment. Amendments for capping include the full range of sediment treatment amendments discussed in Chapter 4.

5.1 Conventional and Amended Capping Background Information

Sediment capping has been used at locations around the world. In the United States, capping was first used as a remedial approach to contain contaminated dredged materials placed in open water in central Long Island Sound beginning in 1978. Since then, more than a hundred contaminated sediment site remedies have included capping. In addition, backfill capping has been used at many sites to isolate residual contamination following dredging efforts. Capping also has been commonly used to manage harbor sediments and other dredged material in the northeast and western United States and is increasingly being used for inland lakes and rivers. Section 5.7 includes summaries of numerous case studies that document capping experience nationwide.

5.2 Capping Objectives and Approaches

Capping is designed to achieve one or more of the following objectives depending upon the cause of exposure and risk at a site:

- *Stabilization* of contaminated sediments prevents resuspension and transport of contaminants to other sites.
- *Chemical isolation* of contaminated sediments reduces migration and release of contaminants from interstitial waters of the underlying sediment.
- *Protection of the benthic community* prevents the benthic community from interacting with and processing the underlying contaminated sediments.

The first objective, stabilization, is achieved by designing a cap of adequate thickness or sufficient armoring to reduce or eliminate erosion of the underlying sediment. The placement of coarse material (typically gravel, cobble, or rock) reduces erosion of the cap and is called "armoring." Sand, gravel, and stone are typically used for these caps. This type of cap can also be termed a "physical cap" because it is primarily designed for physical separation rather than chemical isolation or containment. The sorption characteristics of a physical cap are irrelevant because it is designed only to contain the underlying sediments, not react with these sediments.

For the second objective, a chemical isolation cap can reduce the concentration and flux of contaminants into the biologically active zone. Generally the thicker the cap, the greater this reduction, although in some instances (such as when there is significant groundwater upwelling through the cap) an alternative cap material might be needed to reduce migration and contaminant release or to minimize movement of contaminants upward through the cap. An alternative cap might be placed to meet objectives such as control of upwelling (low permeability cap), adsorbing or sequestering contaminants (sorptive caps), or facilitating contaminant degradation processes (amended caps).

For the final objective, protection of the benthic community, caps offer particular advantages, because the benthic community can be the most important means for transport and trophic transfer of contaminants. This objective is also the primary goal when placing backfill in dredged areas where the exposed surface is contaminated by residuals, that is, to create a clean layer for biota to repopulate. Because benthic organisms can rapidly mix sediments or caps via bioturbation, the thickness of a cap or backfill should be at least as great as the thickness of the layer effectively mixed by benthic organisms, typically 5-10 cm. Many of the same amendments that are used for in situ treatment can also be used in a cap to enhance the performance of the cap and protect the benthic community.

Meeting one or more of these objectives is the focus of cap design approaches. The most complete set of detailed procedures for site and sediment characterization, cap design, cap placement, and monitoring of subaqueous caps can be found in *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (USEPA 2005a) and *Guidance for In situ Subaqueous Capping of Contaminated Sediments* (Palermo et al. 1998). In addition, references that discuss physical considerations, design, and monitoring requirements for capping include, but are not limited to, the following:

- *Review of Removal, Containment, and Treatment Technologies for Remediation of Contaminated Sediment in the Great Lakes* (Averett, Perry, and Miller 1990)
- *Design Requirements for Capping* (Palermo 1991a)
- *Site Selection Considerations for Capping* (Palermo 1991b)
- *Standards for Confined Disposal of Contaminated Sediments Development Document* (WDOE 1990)
- *Equipment and Placement Techniques for Capping* (Palermo 1991c)
- *Monitoring Considerations for Capping* (Palermo, Fredette, and Randall 1992)
- *Subaqueous Capping of Contaminated Sediments: Annotated Bibliography* (Zeman et al. 1992)
- *Design Considerations for Capping/Armoring of Contaminated Sediments In-Place* (Maynord and Oswalt 1993)
- *Subaqueous Cap Design: Selection of Bioturbation Profiles, Depths, and Rates* (Clarke, Palermo, and Sturgis 2001)

- *Subaqueous Capping and Natural Recovery: Understanding the Hydrogeologic Setting at Contaminated Sediment Sites* (Winter 2002)
- *Proceedings: In situ Contaminated Sediment Capping Workshop* (EPRI 2003)
- *Equipment and Placement Techniques for Subaqueous Capping* (Bailey and Palermo 2005)

Recent developments in capping, particularly amended capping, are not addressed by the documents listed above and any proposed capping program should be based on a review of current literature. Many of the recent advances in capping have arisen from the development of a variety of alternative adsorptive and reactive material amendments that enhance cap performance. These materials include organophilic clays for the effective containment of NAPL, AC to enhance sorption and retard migration of dissolved contaminants (particularly organics), and a variety of other materials designed to control specific contaminants or respond to site conditions.

Full-scale cap installations have been completed that include recent improvements in erosion resistance, groundwater upwelling reduction, chemical isolation, and slope stability. These design enhancements can also help in managing problems specific to some sites, such as designs to channel upwelling groundwater or gas from a contaminated site layer (McLinn and Stolzenburg 2009a). Models designed to assess long term cap performance for the purposes of design or performance monitoring have also been improved (Lampert, Reible, and Zhu 2007, Lampert, Lu, and Reible 2013).

5.3 Design Considerations

Cap thickness often determines the effectiveness of the cap (Palermo et al. 1998). Typically the thicker the cap, the greater the reductions in pore-water concentration in the near surface and the greater the reduction in contaminant flux through the cap. Thicker caps are particularly effective when groundwater upwelling is low (for example, less than 1 cm/month) and diffusion dominates contaminant migration. Under conditions of minimal groundwater upwelling for contaminants that are strongly sorbed to sediment solids, the critical function of the cap is to isolate bioturbating organisms from the underlying contaminated sediment. Almost any cap material, including relatively inert sand and gravel, can be an effective cap in these conditions as long as the thickness of the cap layer exceeds the depth of active organism mixing. When groundwater upwelling is significant (typically when upwelling velocities are on the order of 1 cm/day or more), however, an inert cap can be quickly compromised. These conditions may require amendments that can more effectively manage contaminant migration. For example, amendments that sorb and retard contaminant migration may be added, similar to in situ treatment of sediments.

Cap placement is another key design consideration. The placement of a cap depends on the physical properties of the material being placed, the sediment on which it is being placed, and the flow characteristics and depth of the water body. Normally, granular material is simply placed near the surface of a water body of minimal energy, and the material is allowed to gently settle through the water column. Granular material can also be placed using mechanical methods or by making a slurry with water for hydraulic placement, and then allowing the material to settle. Any material with a wet density greater than that of water can be placed by settling.

Some poorly settling materials, such as AC, typically require pre-wetting to displace air that can make the material buoyant. Poorly settling materials or materials placed in a relatively high flow environment may be placed using a submerged diffuser plate, clamshell, or other bucket that can bring the cap material closer to the sediment surface. Direct placement of poorly settling material, such as AC, may be difficult in high flow environments. Composite materials, such as AquaGate, placement in geotextiles, or active media-filled geotextiles can be used for improved cap placement. Placement of geotextile is generally conducted by mechanical means or by divers. Active media-filled geotextiles (such as Reactive Core Mat) are often thin, with relatively low cap material capacity (for instance, less than 1 lb/ft^2) but can also be constructed with thicker gabions that provide larger quantities of the cap material (Marine Mattress). Articulated block or other armored mats may also be used to place and retain cap materials.

Cap design must also account for sediment stability. Usually, capping material is placed in a relatively uniform layer without significant point loading that might destabilize the underlying sediment. Placement in multiple, thin, uniform lifts minimizes differential settling and allows thicker cap layers to be built. Sand layers 2 ft thick (buoyant loading of approximately 120 lb/ft^2) have been placed in this manner onto sediments with a surface shear strength of less than 50 lb/ft^2 (Mansky 1984; Bokuniewicz 1989; Bruin, Van Hattem, and Wijnen 1985; Zeman and Patterson 1996a and b; Palermo, Francinques, and Averett 2003; Thompson, Wilson, and Hansen 2004; Bailey and Palermo 2005; Reible et al. 2006).

5.3.1 Conventional Capping

Conventional capping generally uses natural, largely inert materials in a loose-placed form for physical and chemical isolation. Sand or similar granular material is often the first choice for conventional capping and provides a physical isolation barrier to sediment transport and biological intrusion into the contaminated sediments. Sand is easily placed and, in the absence of facilitated transport mechanisms (such as rapid groundwater upwelling), can be effective at containing not only sediments but also the hydrophobic, solid-sorbed contaminants that they contain. Sand also results in reducing conditions in sediments, which aid in the retention and containment of metals such as lead, zinc, nickel, and copper.

Other natural materials may be used, including dredged material and sediments or soils from nearby locations. Often these natural materials contain fine-grained components, which may make placement more difficult but may also aid in reducing the permeability of the placed cap by reducing or diverting upwelling groundwater. These materials may also contain organic matter that can aid in retention and retardation of both organic and inorganic contaminants. Although the primary focus of this document is on recent developments in capping, natural capping materials are cost effective and often yield results equivalent to results achieved with newer engineered materials.

Several examples of conventional cap materials are summarized in Section 5.7 (see Table 5-3).

5.3.1.1 Sediment Conditions for Conventional Capping

Conventional caps are generally effective under the following conditions:

- strongly solid-associated contaminants (effective K_d>1,000 L/kg in underlying sediment)
- strongly solid-associated contaminants that are effectively contained by control of the mobility of the solids
- strongly solid-associated contaminants that exhibit low interstitial water concentrations and migrate slowly in stable sediment or cap environments

Conventional caps are also effective when contaminants are not subject to facilitated transport, which includes the following conditions:

- contaminants strongly associated with solids
- low colloidal-associated fraction of contaminants
- absence of mobile NAPL

Some sediment conditions can support a cap or the use of geosynthetics to provide reinforcement, including:

- sediments of sufficient bearing capacity to support a cap of the desired thickness (including anticipated over-placement of additional material) or the use of placement methods (such as uniform placement in thin lifts) designed to strengthen the cap
- sufficient slope stability in the underlying sediment to avoid destabilization by either placement or the static load of the cap
- a sediment slope less than the angle of repose of potential cap material (otherwise, additional cap placement may be needed at the base of the slope to create stable slope conditions)
- suitability for geosynthetics to stabilize underlying sediment

Site conditions that minimize capping-related modifications to bottom elevation include:

- future uses, navigation requirements, or habitat requirements that do not limit depth reductions, or pre-dredging or compression loading with the cap can be conducted to minimize or eliminate depth reductions
- strongly solid associated contaminants, which may be effectively contained by thin-layer caps (less than 1 ft)
- low flow environments where armoring requirements are minimal

Site conditions that increase cap stability include:

- deep water
- low erosive forces including low flow, limited wave effects, and limited navigation-related prop wash
- suitability for effective armoring against incident erosive forces

5.3.1.2 Sediment Conditions that Limit Conventional Capping

Sediment or contaminant conditions that are conducive to capping have corresponding conditions that discourage the use of capping. For example, the presence of facilitated transport processes such as mobile NAPL, high potential for colloidally-associated contaminant transport, rapid groundwater upwelling, or deep hyporheic exchange discourage capping, unless cap amendments can offset these conditions.

Note that the presence of one or more conditions that might discourage the use of capping does not necessarily mean that a particular alternative remedy is preferred. The presence of mobile NAPL, for example, is also not easily managed by dredging, because dredging increases the release of the NAPL to the overlying water. Dredging is a solids management technology and is not designed to manage these releases into water. A combination of source control, dredging with special controls, and capping with amendments to directly manage the mobile NAPL may all be needed to implement a successful remedy at such a site.

The following conditions may limit the effectiveness of a conventional cap, particularly one that contains an inert material such as sand:

- weakly-sorbed contaminants that are relatively mobile in the environment (sediment-water partition coefficient of 1,000 L/kg or less [Log K_{ow} <4])
- conditions in the interstitial water that significantly enhance contaminant mobility such as rapid groundwater upwelling or tidal pumping (upwelling velocities of 1 cm/day or more)
- The presence of a mobile NAPL (greater than 5–10% by weight)
- gas ebullition at a rate sufficient to cause substantial contaminant migration (rates of greater than 1 L/m^2/day), requiring further assessment and control
- highly concentrated or especially toxic contaminants, for which even low rates of migration may lead to unacceptable concentrations or fluxes at the cap-water interface or into the overlying water

Weakly-sorbed contaminants, the rapid exchange of interstitial water in the cap, or both in combination often hinder cap effectiveness. In some cases, a more robust conventional cap design can offset these conditions with a thicker sand cap or by use of natural soils or sediments with greater containment characteristics. A thicker sand cap reduces sediment-surface water exchange rates and retards contaminant migration through the cap. A sufficiently protective design may, however, be infeasible or require a cap of unacceptable thickness (causing the water depth to be less than required for future uses of the waterway). The design thickness required to achieve some performance criteria such as maintaining a low concentration or flux in the BAZ is normally defined by a model of contaminant migration and fate in the cap. When high upwelling velocities or mobile contaminants are present, a sediment cap several meters thick may be needed to achieve desired concentrations or fluxes in the surface BAZ.

5.3.2 Amended Capping

When conventional capping is not feasible, amended capping may offer a more protective and potentially less intrusive option. Amended capping is defined as the use of any materials which may interact with the cap or the contaminant to enhance the containment properties of the cap. Using alternative materials to reduce the thickness or increase the protectiveness of a cap is also sometimes termed "active" or "reactive" capping.

An amended cap is used to meet one or more of the following objectives:

- Reduce permeability at the sediment-water interface in order to limit interstitial water exchange processes, such as groundwater upwelling or tidal pumping.
- Increase the sorption capacity of the cap layer, which reduces the thickness of the cap needed to retard contaminant migration.
- Enhance contaminant transformation and degradation processes in order to reduce or eliminate contaminant release into the overlying water.

A variety of amendments are proven to achieve the first two goals; however, few demonstrated options exist for enhancing contaminant transformation and degradation processes. Conventional caps inherently encourage transformation and degradation processes to some degree. Caps create reducing conditions in the sediment layer below the cap by reducing oxygen flux into the sediments. This reduction in oxygen flux can immobilize metals by forming relatively insoluble metal sulfides and can potentially encourage transformation and degradation processes that occur under anaerobic conditions (such as reductive dechlorination). A cap also can reduce organic carbon deposition into the sediments, thus reducing microbial activity that can lead to methylation of mercury but also reducing microbial degradation activity for target contaminants. Documented attempts to further enhance these transformation and degradation processes with amendments include the following:

- The addition of calcium nitrate significantly reduced PAH concentrations within a year (Murphy, Moller, and Brouwer 1995).
- The addition of slow-release fertilizers to contaminated beach sands significantly enhanced degradation rates of two- to six-ring PAHs (Xu and Obbard 2004).

Few other applications of nutrient amendments for biodegradation enhancement have been conducted in the field, primarily due to the difficulty of introducing amendments and the need to replenish the nutrients after some time. Some work on this approach, however is underway (Yan and Reible 2012; Chun et al. 2012).

5.3.2.1 Amendments for Capping

Active capping for permeability control or to retard migration through sorption is a developed technology that has been demonstrated in the field. A wide range of materials are available for amended active capping. Some of the key amendment materials and their properties are discussed below.

Activated Carbon

Activated carbon (AC) strongly sorbs organic compounds that are commonly associated with sediments and thus is widely studied as a potential treatment amendment. Placement of AC for sediment capping is difficult due to the near neutral buoyancy of this material. One procedure for placing a thin layer of near neutral buoyancy material uses a Reactive Core Mat (McDonough et al. 2007). Using the mat, a thin layer of coke (an inexpensive, moderately sorbing material) was placed in a capping demonstration in the Anacostia River (Reible et al. 2006). The success of this technique showed that placing a high cost material such as AC in a controlled manner is feasible. Since the early demonstrations, other delivery systems for AC have been successfully piloted, including AquaGate+PAC (a powder AC delivery system that uses the AquaBlok technology) and SediMite (Ghosh et al. 2011; Menzie 2012).

Additional research, both completed and ongoing, supports the use of AC as a treatment amendment for sediments. Modeling of the transport of organic contaminants through thin-layer AC caps has shown that AC can isolate PCB-contaminated sediment for greater than 60 years, even with groundwater upwelling rates as high as 1 cm/day (Murphy et al. 2006). Batch adsorption experiments have demonstrated the effectiveness of AC for sediment capping in the presence of natural organic matter, which is usually present in sediment environments (McDonough, Fairey, and Lowry 2008; Sharma et al. 2009). The natural organic matter significantly lowered the adsorption capacity of the carbon, although the sorption of PCBs onto the carbon was still sufficient to warrant further study of AC as a capping material. The presence of NAPL may also have significantly affected the sorption capacity of AC.

Apatites

Apatites processed from animal bones and mined fossilized bones, such as from fish, are a class of naturally-occurring minerals that have been investigated as a sorbent for metals in soils and sediments (Conca and Wright 2006; Chen et al. 1997; Peld, Tõnsuaadu, and Bender 2004). Apatites consist of a matrix of calcium phosphate and various other common anions, including fluoride, chloride, hydroxide, and occasionally carbonate. These minerals sequester metals either through direct ion exchange with the calcium atom (Miyake, Ishigaki, and Suzuki 1986; Takeuchi and Arai 1990) or dissolution of hydroxyapatite followed by precipitation of lead apatite (Ma et al. 1993; Xu and Schwartz 1994). Pilot-scale apatite caps have shown reductions in lead, cadmium, and zinc pore-water concentrations and reduced bioaccumulation of cadmium as compared to control (sand) caps (Crannell et al. 2004). One successful implementation of an apatite cap for control of metals was conducted in the Anacostia River in Washington DC (Reible et al. 2006). Solid-phase concentration profiles suggested effective containment of the underlying contaminated metals six months after cap installation.

Organophilic Clays

Organophilic clays are created by introducing a cationic surfactant onto the surface of clays such as bentonites. These clays can be used in caps to create a hydrophobic, sorbing layer for nonpolar organics, which is effective for control of NAPLs in particular (Reible et al. 2007). An organophilic clay cap has been used for sediment remediation at the McCormick and Baxter site (Parrett and Blishke 2005; Reible, Lu, and Blishke 2005) and several other sites. One study found that 2,4-dichlorophenol was adsorbed effectively onto organophilic clay in laboratory isotherm experiments; researchers were also able to model transport of the solute through an organophilic clay column using the convection-dispersion equation (Pernyeszi et al. 2006).

Zeolites

Zeolites are microporous aluminosilicate minerals with a high cationic exchange capacity (CEC). Theoretically, zeolites should be effective in an active barrier system for containment of metals (Jacobs and Forstner 1999). One study found that zinc and iron were effectively demobilized using a zeolite-based amended capping system (Jacobs and Waite 2004). These materials have not yet been applied in the field for sediment remediation.

Low-permeability Clays

As an alternative or addition to other more common sorptive capping amendments, low-permeability clay amendments have been installed at full-scale to enhance cap performance and design life by decreasing pore-water advection. Low-permeability clays effectively divert upwelling groundwater away from a contaminated sediment area but are difficult to place in the aqueous environment. Bentonite clay placed in mats is also known as a geosynthetic clay liner (such as Bentonite CL). These mats have been used as a low-permeability cap at several sediment projects including the Galaxy/Spectron, Marathon Battery, and Lower Duwamish sites.

Commercial products are available that can place clays directly through the water column. AquaBlok, a bentonite clay- and polymer-based mineral formed around an aggregate core, is one effective sediment capping material (Hull et al. 1998). AquaBlok can settle to the bottom of the water column and form a cohesive boundary with minimal intermixing with the underlying contaminated sediment and with permeabilities on the order of 10^{-9} cm/sec. One successful implementation of an AquaBlok cap for permeability control was conducted in the Anacostia River in Washington, DC (Reible et al. 2006). Initially after placement, the AquaBlok cap effectively reduced the pore-water advection rates to zero, versus a control area and a sand cap. Gas accumulation and ultimate release led to substantial movement of the low-permeability layer and potentially a reduction in long-term containment (Reible et al. 2006).

Placement and incorporation of clay materials into amended caps has been performed at dozens of full-scale installations throughout the United States and success of the approach has been documented in five-year monitoring events at Superfund sites such as the Tennessee Wood Products site on Chattanooga Creek. Permeability control with clay materials can be used in effective cap designs as long as gas or water upwelling is negligible or managed by the design.

Nutrients

The addition of materials for enhancing the attenuation of halogenated organic compounds through biodegradation has also been assessed and is showing promise (Reible, personal communication, 2013).

Zero-valent Iron

Zero-valent iron (ZVI) nanoparticles are an increasingly popular amendment for soil and sediment remediation (Li, Elliott, and Zhang 2006). ZVI particles have a reactive surface that can chemically reduce and subsequently immobilize a variety of compounds. Degradation of mixtures of PCBs and other chlorinated solvents have been reported through reactions with ZVI (Wang and Zhang 1997). Other laboratory-scale feasibility assessments have shown the potential for the use of ZVI to treat nitroaromatic compounds (Agrawal and Tratnyek 1995), arsenic (Kanel et al. 2005), chromium (VI) and lead (II) in aqueous solutions (Ponder, Darab, and Mallouk 2000), and dichlorodiphenyltrichloroethane (DDT) and related compounds (Sayles et al. 1997). More pilot and field-scale demonstrations are needed, however, to assess the long-term feasibility of ZVI as a sediment capping amendment. Preliminary laboratory studies suggest that the passivation (formation of an oxide layer on the reactive surface) of the iron in the aqueous environment may preclude its use in a sediment cap.

5.3.3 Resuspension and Other Capping Effects

Potential effects of cap placement (conventional or amended) include the following:

- increases in turbidity or suspended sediment in the water column
- resuspension of contaminated surface sediments
- destabilization of the underlying sediment, causing slope failure and resuspension of contaminated sediment

After placement, the cap may alter the substrate characteristics and therefore its habitat characteristics. The cap can also reduce water depths, further influencing habitat characteristics and potential future use. Note that cap material can be selected to improve habitat characteristics for a particular species of concern.

Adverse effects during construction can be minimized by gentle, uniform placement of the cap material (for example, by placement in thin lifts and allowing for natural cap material settling). The potential for destabilization of an underlying slope or bearing capacity failure can be assessed by geotechnical engineering analysis (Otten and Hartman 2002). In the absence of underlying sediment failure, some resuspension of sediment may still occur, although this resuspension is not expected to approach the level of resuspension that occurs with dredging.

5.4 Data Needs for Cap Design

Four general categories of data are typically needed for cap design: physical site characteristics, sediment characteristics, contaminant characteristics, and land and waterway use. Table 5-1 summarizes the data collection needs to support cap selection and design.

Table 5-1. Data collection needs for capping design

Information Need	Recommended Data Collection (Calculations, Tests, or Measurements)	Design Component
Physical Characteristics		
Hydrologic Conditions	Bottom current measurements	Cap stability is a function of bed shear stress (the forces created by the action of moving water, waves, or propeller wash on the sediment surface). In order to determine sediment stability and armoring needs to protect cap integrity, velocity measurements are required. Note that in some estuarine systems salinity stratification may occur (due to buoyant freshwater flowing over salt water). In those cases, it may also be necessary to measure the effects of stratification on flow.
	Water column suspended solids and bed load sampling	Data used to estimate natural recovery and/or recontamination potential. Of particular importance in areas where there are still up current sources of unremediated contaminants. If sediment transport modelling is conducted, then suspended solids/bed load data can be used to calibrate the model.
	Shear stresses: Sedflume or SEAWOLF, or other similar erosion testing devices	Critical shear-stress measures, along with bottom current measures, describe the conditions under which cap sediments can be resuspended and erode. While typically done under a range of potential system flow conditions, the critical shear stresses needed for cap design are those that occur under extreme weather events, such as 100-year floods, 100-year return storms, or ice scour conditions.
Sedimentation/ Recontamination Potential	Sediment traps: gross sedimentation	Sediment traps measure time-rate of sedimentation and associated sediment quality. These data may be used to determine (1) the potential for recontamination of the cap surface from outside sources and (2) sedimentation rates that may be used in conjunction with advective or diffusive flux modeling.
	Core profiles: radioisotope and fine-resolution chemical profiling	Evaluation of radioisotopes in cores, as well as fine-resolution chemical profiling provide a second basis for evaluating recontamination potential and net sedimentation rates for future performance estimates.
Sediment-Water Flux Rates	Measure flux of COCs; tools such as Trident Probe, Ultra Seep Meter, or piezometers can be used to directly measure contaminant flux through sediments	Flux rates are needed to evaluate (1) levels of COCs advecting through the sediment-water interface, and (2) provide pore-water velocity rates for use in advective and diffusive flux modeling.

Table 5-1. Data collection needs for capping design (continued)

Information Need	Recommended Data Collection (Calculations, Tests, or Measurements)	Design Component
Surface Water Runoff	Source identification and chemical measures of inflow Dye-tracing studies from large CSO/storm drains	In urban industrial areas, adequate source control is generally needed prior to implementing a remedial alternative or else quantified to determine recontamination potential and acceptable limits associated with this potential. Where required, runoff contributions may be an additional input to a fate and transport model.
Sediment Characteristics		
Chemical Nature and Extent	Solids: COPCs, TOC, other parameters as needed	Contaminant distribution profiles needed to delineate horizontal and vertical extent of remedial area. A general rule is four cores/acre. More may be needed to delineate NAPL pathways.
	Pore water: COPCs, TOC, DOC, other parameters as needed	Capping design requires both solid and pore-water contaminant data as input into advective and diffusive flux modeling.
	NAPL surface and subsurface distribution	NAPL distribution information needed to understand if removal is practical, whether capping will contain or cause NAPL movement due to displacement by cap weight, or whether NAPL is effectively buried under existing foundation sediments.
	Groundwater - VOCs, SVOCs, metals, other chemicals as needed	Groundwater measures are needed to determine whether upland contaminants may be advected into the cap.
Geotechnical Properties: In-river sediment	Grain size: ASTM D422	Sediment grain size data are used to assess compressibility as well as to estimate porosity for advective and diffusive flux modeling. In addition to the native sediments, grain size of the capping material should be measured to assist in determining application methods and rates, sediment transport or erodibility modeling, and habitat conditions.
	Bulk unit weight: ASTM D2937	Physical properties needed to assess the stability of foundation sediments for capping.
	% solids: ASTM D2216	
	Specific gravity: ASTM D854	
	Atterberg limits: ASTM D4318	
	Consolidation: ASTM D2435	
	Shear strength: ASTM D2573 (field vane shear test); ASTM D2850 (laboratory triaxial compression test; requires undisturbed Shelby tube-type cores)	

Table 5-1. Data collection needs for capping design (continued)

Information Need	Recommended Data Collection (Calculations, Tests, or Measurements)	Design Component
Biological Characteristics		
Benthic Infaunal Communities	Collection and characterization	Infaunal counts are used to establish baseline conditions, and to determine the presence of deep-burrowing fauna that may impact the cap design.
	Sediment profile imaging	Mixed layer thickness refers to the baseline surficial biologically mixed layer of sediments (BAZ). The depth of the mixed layer is used in advective and diffusive flux models. Sediment profile imaging provides a photograph that represents a direct measure of the foundation sediment BAZ.
Biological: valuable habitat areas	Visual reconnaissance; consult with local biologists	Identification of valuable habitat areas will influence the spatial extent of active remedies as they relate to net environmental benefit.
General Construction Requirements		
Survey Control	Establish permanent benchmarks using NAD 83/91 or equivalent state plane coordinate system.	Provides a consistent basis for vertical and horizontal positioning for the pre-design sampling, and later for remedial construction on, or adjacent to, the water body.
Surface Elevations	Single-beam or multi-beam sonar supplemented with lead lining or topographic survey in shallow water.	Measurements of sediment bed elevation profiles are needed to: (1) provide information on baseline conditions; (2) estimate how the changes in cap elevations affect potential erosional conditions; (3) evaluate changes in flood potential; and (4) assess current and future habitat conditions.
Bottom and Subbottom Profiling	Side scan and multi-beam sonar	Information on water depth, extent of soft sediments, in-water and subsurface sediment obstructions or debris are needed to assess and select remedies. Subbottom profiling may provide information on extent of methane pockets
Structures Survey	Visual reconnaissance and/or aerial or satellite along shoreline areas	In active industrial areas these surveys provide information on the presence, condition, and accessibility of under-pier areas. Piling structures can influence fate and transport properties, dredging feasibility, and access to affected sediments.
Land and Waterway Use		
Land and Waterway Use: waterway, recreational, local tribes and public	Site reconnaissance along and near shoreline areas	Areas designated for public and tribal use could affect the feasibility of potential remedial alternatives including extent, cleanup levels, duration, and expectations.

5.4.1 Physical Site Characteristics

Analysis of physical site characteristics helps to determine the degree to which a bed can support a cap, whether sediment conditions are conducive to capping, and the characteristics of the water body through which the cap material must be placed. The following sections describe the key physical characteristics to consider when evaluating capping as a potential remedy.

5.4.1.1 Hydrodynamics and Erosional Estimates

Meeting long-term performance goals depends on whether the cap can be maintained in place for its design life. Data regarding local hydrodynamics and erosion can help designers maximize cap life and reduce the potential for resuspension.

The cap must be resilient to erosive pressures from the overlying water body. The erosional resistance of the underlying sediment is unimportant, because the surface exposed to potential erosion is the cap and not the sediment. Normally caps are designed to resist erosion during expected flow events or other erosional forces (such as propeller wash). Some erosion can be acceptable, however, if it does not significantly compromise the function of the cap. For example, spatially-isolated erosion near a dock may not compromise the overall performance of the cap. In addition, short-term erosive events may lead to loss of the upper portions of the cap but may leave sufficient cap thickness to maintain performance. Site specific assessment of potential erosive forces and implications is required. *Currents greater than 1 ft/s increase the difficulty of sand cap placement and the potential for erosion.*

The likelihood of erosion of a cap subjected to a particular erosive force is well understood for the noncohesive granular materials that constitute many caps and for almost all material used to armor a cap. In some cases, the erosion performance characteristics of a cap may be improved through the incorporation of other, more cohesive materials. In any event, the primary design challenge is to define the magnitude, duration, and frequencies of events that might lead to erosion of the cap. Common benchmarks include a 100-year storm event or a watershed design flood, wind-driven waves for shallow waters or emergent caps, and for water bodies challenged by navigation, the erosive forces associated with normal operation of the largest and most powerful vessels that might influence an area. Site-specific issues that may be relevant include ice jams that might lead to extraordinarily high erosive forces or seismic activity that may compromise sediment caps, particularly on unstable subsurface slopes.

5.4.1.2 Depositional Rate

Many areas that require sediment remediation are net depositional, and the assessment of deposition rate as well as the quality of those accumulating sediments can be useful data for cap design. Although these areas may be subject to scour during storm and other irregular events, the presence of sediment contaminants, often decades after release into the environment, is due to the net accumulation of sediments. If contaminant sources are adequately controlled, then any continued deposition of sediments leads to a natural capping of existing sediments. *Net deposition within an area provides improved performance of any cap in that area.*

Capping in these situations is effectively a means of shortening the time required for natural recovery by placement of a cap layer of a thickness equivalent to the thickness of material that would accumulate over a given period of natural deposition. Moreover, continued deposition increases the effective thickness of a capping layer over time. Deposition at a rate faster than the rate of migration of contaminants results in a cap that becomes increasingly protective over time.

5.4.1.3 Water Depth

Water depth is another key physical characteristic relevant to cap selection and design. Water depth may be important to retain conditions appropriate for a particular species or to maintain navigability or flood control capacity. Placement of a cap may reduce the water depth and limit the ability of the remedy to meet these design criteria. Appropriate water depths should be assessed during design and a cap design modified to meet those requirements. *Generally water depths less than 5 ft or greater than 50 ft tend to require special equipment and techniques for adequate cap placement. For instance, water depths of less than 5 ft may require shallow draft boats and where water depth is greater than 50 ft, the placement of cap material is difficult to control.*

Cap design should include an assessment of the consolidation of underlying sediment that may partially or completely offset any reduction in water depth with a cap. If reduction in cap thickness is required to maintain adequate water depth, then cap amendments may be needed to offset any potential reduction in performance due to the reduction in thickness. Another option is to dredge the area sufficiently to allow placement of a cap of design thickness.

5.4.1.4 In-water Infrastructure and Debris

In general, a sediment cap can be placed atop in-water infrastructure or debris. Thus, these issues do not normally influence cap design except in the case where access to that infrastructure is required (such as for pipeline or power line maintenance or replacement). *Erosional forces are likely to be greater around certain structures and may promote localized scour and prevent uniform coverage, requiring additional armoring to keep the cap in place.*

5.4.1.5 Slope Stability

Placement of a cap and its subsequent integrity requires that the underlying sediment will not collapse due to cap placement. *Slopes with a low factor of safety for stability (less than 1.5) and low undrained shear strengths (less than 20 psf or 1 kPa) may require special considerations for cap design, thickness, and placement methods.*

Excessive loading of a slope may result in failure of that slope and subsequent failure of the risk reduction characteristics of a cap. Seismic activity can also destabilize slopes. Neither loading of a slope nor slope failure necessarily results in cap failure, but the effects of such phenomena should be assessed as part of the cap design. Geosynthetics (such as geotextiles and geogrids) can help to reinforce slopes.

5.4.1.6 Sediment Bearing Capacity

Closely related to slope stability is sediment bearing capacity—the degree to which a horizontal sediment bed can support the load of a cap. This characteristic is conservatively assessed by determining whether the sediment can support a point load. Low bearing capacity of an underlying sediment requires placement of a cap in thin uniform lifts (potentially with a waiting period between lifts), which provides a distributed load and allows excess pore pressure dissipation and sediment consolidation and strengthening before the full cap thickness is placed. Geosynthetics (such as geotextiles and geogrids) can help strengthen sediments, although a geosynthetic that might clog, thus reducing gas or water movement, should be avoided.

5.4.1.7 Advective Groundwater Flux

The movement of groundwater through a cap often controls the cap's capacity to effectively contain contaminants. Measurement of groundwater flow rate and the contaminant concentration in that groundwater (pore water) is required to evaluate the contaminant flux that a cap must control. Contaminant migration in groundwater upwelling of greater than 1 cm/day is dominated by advection, while diffusion typically controls contaminant migration when groundwater upwelling is less than 1 cm/month. *Areas with a groundwater upwelling rate of less than 1 cm/ month are rarely a concern; however, a rate of 1 cm/day is likely to be advection dominated and may require an amended cap or upland groundwater control.*

Groundwater upwelling is one of the most difficult cap parameters to assess because it often occurs at a low rate and is spatially variable. Point measurements in the water body may significantly misrepresent groundwater upwelling if they are located in areas of low flux. Often the best estimate of mean groundwater upwelling is obtained by measuring upland groundwater advection, since the water delivered across the sediment-water interface cannot exceed that delivered from the upland. To be relevant to contaminant flux, however, the concentration of contaminants in the mobile phase pore water must be assessed by direct measurement or inferred from solid-phase concentrations, if an appropriate partition coefficient can be determined.

Advection induced by either a mean groundwater gradient or by tidal changes in groundwater gradients may require a cap design that includes active elements, such as sorbents to slow contaminant migration or layers that encourage degradation of the contaminants.

5.4.1.8 Sediment Geochemistry

The capacity of a cap to contain particular contaminants may also be a strong function of sediment geochemistry. This characteristic is particularly important for inorganic contaminants. Strongly reducing sulfidic sediments generally contain divalent metal contaminants such as lead, nickel, cadmium, zinc, and copper, because these species form metal sulfides and then precipitate. Strongly reducing sulfidic sediments also tend to control mercury release and methylation. A small amount of sulfide formation, however, may increase mercury methylation and mercury mobility. Oxidized sediments near surface sediments, or sediments subject to significant groundwater-surface water exchange or variations in benthic boundary layer oxygen levels typically induce metal oxidation, pH changes, and increased metal mobility. These variations typically occur at the surface of a cap, whereas strongly reducing conditions, which influence contaminant fate and behavior, are likely dominant at the base of a cap.

For organic contaminants, sediment geochemistry primarily influences microbial degradation and transformation rates. Hydrocarbons and PAHs tend to exhibit slow or minimal degradation under the reducing conditions typically found at the base of a cap. Partial dechlorination of chlorinated compounds may occur under reducing conditions, but site-specific information is usually required to support the assessment of fate processes in reducing sediments.

5.4.2 Sediment Characteristics

5.4.2.1 Geotechnical Characteristics

The primary concerns for the sediment on which a cap is to be placed are sediment strength (load bearing capacity) and consolidation characteristics. Horizontal sediments are discussed here; sloping sediments require specific evaluation for slope stability. For example, a cap with an undrained shear strength of 1kPa (20 psf) can support a sand cap approximately 2 ft thick (or 1 ft thick with a safety factor of 2) based on a point loading calculation, although the disturbance associated with placement could cause failure. *Sediments with undrained shear strengths less than 1 kPa (20 psf) may require special considerations on cap design, thickness (such as less than 2 ft of sand), and placement methods (see Section 5.5).*

Sediments consolidated by the placement of a cap express pore water from the underlying contaminated sediments. The zone that may be affected by migration of the pore water is likely to be minimal in situations where contaminants sorb to cap material, but for nonsorbing cap materials this migration may be an important transient phenomenon.

5.4.2.2 Organic Carbon and Sorption

The presence of organic carbon (for hydrophobic organic contaminants) and general sorption characteristics limits the amount of contaminant present in the pore water. For a stable sediment cap, only the contaminants present in the pore water may migrate up into the cap layer and to the overlying water. Sorption onto natural vegetative matter or to anthropogenic carbon (soot or hard carbon) can dramatically limit the amount of contaminant that can migrate into the cap. For metal contaminants, the sorption processes are more complicated, but again only those contaminants present in the pore water can migrate as a result of diffusion, groundwater advection, or consolidation. Measurement of dissolved and particulate organic carbon (DOC and POC) in sediment systems is complicated by the difficulty in separating the dissolved and the sorbed phases. Passive sampling approaches that are based upon chemical partitioning (rather than filtration) can help achieve this separation. Some observations suggest that the passive sampler measurement of interstitial water concentration is a better indicator of bioavailability and organism effects than bulk solid concentration (Lu et al. 2011).

5.4.2.3 Bioturbation

Bioturbation can be one of the most important contaminant migration processes in sediments and thus is an important consideration for cap evaluation and design. Sediment-feeding organisms, in particular, move sediment and contaminants associated with that sediment as a result of burrowing and feeding activities. The depth and intensity of the mixing processes thus control contaminant migration and fate. Rooted plants may also contribute to the depth of the BAZ in some instances, although the intensity of associated mixing processes may be small. *In general, the thickness of a cap should be greater than the BAZ within the cap.*

Note that a cap need not be thicker than the depth of all organism activity. Some organisms may penetrate deeply, but most organisms and significant mixing activity is limited to 5–15 cm, or even less in some environments. The primary concern is the depth of sustained, significant bioturbation activity and not occasional deeper penetrations.

5.4.3 Contaminant Characteristic Data

5.4.3.1 Horizontal and Vertical Distribution

The horizontal and vertical distribution of contaminants influence cap design. *The site must be characterized sufficiently to design a cap on the full areal extent of the contamination warranting a cap.* The larger the areal extent of contamination, the larger the cost of any sediment remedy. The vertical distribution may also be important to the long-term performance of a cap. A relatively thin layer of sediment contamination may be completely contained by the sorption with a cap, particularly for an actively sorbing cap. A thick layer of contamination, or a layer with more highly contaminated zones at depth, may result in sustaining or even increasing the contaminant flux through a cap over time.

In other situations, depletion of the contaminant in the upper layers of sediment by migration into the cap may cause substantial decreases in flux over time. Some commonly-used, simple models of cap performance do not account for these complexities, because these models assume that the flux of contamination from the underlying sediment is constant and ongoing.

5.4.3.2 Contaminant Type

Assessment of the type of contaminant and its relative mobility is another critical step in cap design. The potential risks of sediment contamination depend not only on the contaminant concentration, but also on the type of contaminant present. Metals are often effectively contained by a reducing environment, because many metals form insoluble metal sulfides under such conditions. Placement of a cap promotes reducing conditions in the underlying sediment. Organics, however, are often persistent in a reducing environment and thus are not subject to transformations that might limit their mobility. Different organics have widely differing mobilities. Low hydrophobicity organics are relatively nonsorbing and may be far more mobile than more hydrophobic organics. The significance of pore-water advection and diffusion processes may be different for these compounds, with less hydrophobic compounds affected by pore-water processes, while strongly-sorbing, highly hydrophobic organics are largely uninfluenced by pore-water processes.

5.4.3.3 Contaminant Physical Characteristics

The physical and chemical nature of the contaminant is also important. Low-sorbing contaminants, either due to minimal hydrophobicity as a dissolved contaminant or as a component of a separate NAPL phase, can be mobile in sediments. Any groundwater movement may carry the mobile contaminant or NAPL out of the sediments. If NAPL is present at fractions of a few percent or less, however, then capillary forces may render the NAPL largely immobile and contaminants within the NAPL may be largely immobile as well. *NAPL in concentrations of greater than 5–10% by volume may be mobile and require special considerations. Moderate to high mobility contaminants (typically those with sediment-water partition coefficients less than 1,000 L/kg) may require upland groundwater control or sorbing caps.*

5.4.3.4 Background Contamination

Background levels of a contaminant can limit the potential success of a remedy. Background refers to the concentration of a contaminant that is present throughout the water body and is not related to the specific sources that are being remediated. It is generally not feasible to clean sediment sites to concentrations that are below background levels (see Section 2.2). Background should not lead to recontamination that would exceed risk goals.

5.4.4 Land and Waterway Use Data

5.4.4.1 Watershed Source Impacts

As with other remedies, the effectiveness of capping can be offset by continued deposition of contaminated sediments to the sediment surface. Conventional capping does not necessarily result in degradation or transformation of contaminants and deposition of new contaminants can rapidly return the surficial layers to pre-remedy conditions. Complete control of ongoing sources may not be possible, and the long-term implications of any continuing source must be assessed before implementing a capping remedy.

5.4.4.2 Cultural and Archeological Issues

Capping usually does not negatively affect cultural interests (see Section 8.0) in the subsurface environment, other than it may limit access to any relics present. In many cases, capping can be used to protect and isolate cultural or archeological features. *Cap placement methods should preserve cultural and archeological resources.* The presence and ultimate disposition of these resources should be assessed prior to capping so that the isolation provided by capping does not hinder any future excavation plans.

5.4.4.3 Site Access

As with any major remedial operation, capping requires appropriate access to the waterway for staging and processing cap materials. Access is required for storing cap material and transferring the material to delivery equipment. In addition, if some dredging is required to control water depths, solids handling facilities must also be provided.

5.5 Evaluation Process

5.5.1 Protection of Human Health and the Environment

Sediment capping can achieve risk reduction objectives by reducing contaminant flux to the overlying water and reducing concentrations in pore-water and bulk solids at the sediment-water (or cap-water) interface. The short-term risks of contaminated sediments are largely associated with the surface sediments with which benthic organisms interact. The risks from these sediments can be effectively eliminated, at least in the short term, by sediment capping that provides clean substrate at the interface and moves organisms from the contaminated sediment to the top of a cap layer. In the short term, caps can rapidly achieve RAOs. Over the long term, contaminants may ultimately migrate through a cap, although natural attenuation processes may be sufficient to prevent this breakthrough.

5.5.2 Long-term Effectiveness

Cap long-term effectiveness evaluations must include consideration of factors such as groundwater advection, cap erosion, slope failure, and deep bioturbation. Note that the effectiveness of a cap is based upon areal average contaminant levels. Small areas that are compromised by disturbances or failures do not necessarily limit overall or long-term effectiveness.

5.5.3 Short-term Effects

The short-term effects of capping are generally minimal. Resuspension of sediment or turbidity generated by the capping material during installation is limited and can be controlled by appropriate cap placement. Normal controls are simply to slow cap placement or place the cap in thin lifts to minimize negative impacts.

5.5.4 Implementability

Capping is easily and rapidly implemented and a clean sediment surface is immediately present. This rapid progress is a significant advantage, because risk reduction can typically be achieved in a much shorter time than with natural attenuation or dredging. Long-term success, however, depends on whether the cap can maintain containment. Few site conditions affect the implementability of the cap, other than very soft, easily resuspended sediments that may require application in thin lifts. As with any active remedy, proper access and staging areas are critical to successful implementation.

5.5.5 Cost

A significant advantage of capping is its cost effectiveness. The overall cost of removal options are often controlled by sediment processing and disposal costs, which are not incurred in capping. The overall cost of capping is often similar to that of dredging when there are minimal onshore costs (for instance, when on-site disposal is possible). In general, however, the cost of capping is substantially less than dredging options. An offsetting factor, however, is that additional monitoring (and potentially maintenance and site use restrictions) may be required for capping, since contaminants are not removed or destroyed.

5.5.6 Sustainability

Capping, particularly thin-layer capping as in EMNR (see Section 3.2.4), has relatively few adverse effects on the site. A cap affects aquatic organisms less than dredging does because it generates less resuspension and residual contamination. In addition, capping does not require upland sediment processing, transportation, and disposal and associated equipment needed for dredging, which is a significant advantage that reduces environmental impacts of capping (such as greenhouse gases and energy requirements).

5.5.7 Habitat and Resource Restoration

A well-designed cap can improve substrate and provide habitat for aquatic organisms. Often, contaminated sediment sites exhibit poor substrate quality and capping provides an opportunity to improve and restore that habitat. Any habitat created, however, must be consistent with current watershed conditions.

5.5.8 Future Land and Waterway Use

Future land and waterways uses must also be considered with capping. If a specific water depth is required for navigability or desired habitat characteristics, dredging may be needed prior to capping to achieve desired water depths. Requirements for access to utilities, such as power cables and pipelines, may limit or alter capping designs.

5.6 Monitoring

In order for a cap to achieve its desired objectives it must meet the following criteria:

- The cap must be placed properly, which is evaluated by construction monitoring.
- The cap must be maintained in place to allow continued achievement of objectives and evaluated for long-term cap integrity (post-remediation monitoring).
- The cap must achieve long-term performance objectives (post-remediation effectiveness monitoring), as evaluated by chemical and risk monitoring.

Table 5-2 describes the general objectives and measures for monitoring construction, post-remediation performance, and effectiveness of caps. Any parameter used for monitoring construction and post-remediation performance must be included in baseline monitoring to separate background from remedy-associated effects.

Table 5-2. Measures potentially applicable to monitoring objectives for capping

Phase	Objectives	Measures		
		Chemical	Physical	Biological
Construction Monitoring	Determine whether the established performance metrics for remedy implementation or construction are being met.	Turbidity and total suspended solids are used to estimate possible sediment resuspension.	Evaluate proper thickness and composition of cap (for example, organic carbon).	Benthic infauna survey
Post -remediation Performance Monitoring	Determine whether the remedy has been successful in reducing mobility of COCs in sediment (and therefore near-surface COC concentrations) to acceptable levels (RAOs) defined in the remediation decision documents, and whether specific criteria such as cap thickness, composition, and performance are acceptable.	General chemistry	Bathymetry survey	Benthic infauna survey
		Geochemistry	High-resolution acoustic surveys, sediment profile imaging	Benthic infauna survey
		Profiling COCs concentrations	Poling, probing, sub-bottom profiling, and coring	Benthic infauna survey
	Determine whether flux and near surface contaminant concentration remain sufficiently low to protect surficial sediments, benthic community, and overlying water. Fish tissue levels meet (or are expected to meet within some established time frame) the RAOs that are protective of human health as well as piscivorous birds and mammals.	General chemistry	Bathymetry survey	Benthic infauna survey
		Geochemistry	Poling, probing, sub-bottom profiling, and coring	
		COCs concentrations (pore water and near-surface sediments)		

5.6.1 Construction Monitoring

Cap placement is evaluated by measurements such as thickness and composition (for example, organic carbon content) of the completed cap. The design and evaluation of placement must account for the variability and uncertainty in placement and measurement approaches. Typically the thickness and composition should be specified on a statistical basis, such as 95% upper confidence limit on the mean, recognizing that any individual measurement may vary significantly from areal average values without substantially influencing the overall performance of the cap.

5.6.2 Performance Monitoring

The long-term stability and physical integrity of a cap is usually monitored through physical measurements (such as water depth and coring) to confirm cap thickness. The cap thickness can also be measured using high-resolution acoustic survey methods and sediment profile cameras. Since a cap is an area-based remedy, isolated areas that do not meet thickness criteria may not be significant. Instead, statistical measures such as 95% confidence limits on the mean thickness are more relevant performance indicators. Cap continuity can be assessed using underwater video and diver observations. While the cap must be resilient to expected erosive pressures from the overlying water body, some erosion is permissible if it does not significantly compromise the function of the cap.

Monitoring at the surface of the cap does not provide early-warning signs of poor cap performance because caps are designed to require long migration times for contaminant breakthrough or to maintain a low concentration or flux in the surface layers of a cap indefinitely. Cap monitoring may, however, be useful as an indicator of recontamination from uncontrolled nearby sources. Potentially, changes in cap composition over time might also be monitored by coring. Coring can be difficult for armored caps, although in some cases armoring has been removed to allow coring during monitoring. Coring of a nonsorbing cap material such as sand does not provide an indication of contaminant migration if analysis is limited to bulk solid concentrations.

A more sensitive indicator of cap performance is profiling of interstitial water concentration within a cap, particularly if accomplished by in situ passive sampling that is minimally invasive and causes minimal disturbance. This measurement can provide an early indication of contaminant migration and is independent of the sorbing characteristics of the cap material. The interstitial water concentration can be compared to expectations of contaminant migration for example, model predictions, at any time after the cap is placed.

5.6.3 Effectiveness Monitoring

Risk reduction is usually evaluated by long-term performance monitoring of chemical or biological parameters. The primary long-term goal of capping is to provide sufficient containment of contaminants so that either of the following occur:

- The flux and near surface contaminant concentrations in a cap remain low enough that the cap is protective of the surficial sediments, the benthic community residing there, and overlying water.
- The contaminant is contained for a sufficient period to allow natural recovery processes to effectively make the cap irrelevant.

Note that a cap cannot permanently reduce the flux of contaminants to the overlying water to zero. Instead, the goal is to achieve adequate containment to delay or reduce the flux or contaminant levels in the biologically active, surficial sediments to negligible levels or to reduce the flux to the overlying water to levels that can be managed by natural attenuation processes. These processes can include contaminant transformation and degradation in the sediment or water column, but often are simply physical processes that lead to isolation (burial by natural deposition) or dilution of the contaminants.

Effectiveness monitoring of sediment capping is inextricably linked to the cap design and should be linked to the objectives defined by the design. Moreover, the ability to meet those objectives depends on the collection of data necessary to adequately support the design.

5.7 Case Studies for Conventional and Amended Caps

Extensive field experience is available for conventional and amended caps and is summarized in the tables that follow.

- Table 5-3. Representative contaminated sediment capping projects
- Table 5-4. Representative active sediment capping projects
- Table 5-5. Case studies describing conventional and amended capping experience

Other amended cap cases studies are also included in the USEPA document *Use of Amendments for In-Situ Remediation at Superfund Sediment Sites* (USEPA 2013a).

Table 5-3. Representative contaminated sediment capping projects

Project	Contaminants	Site Conditions	Design Thickness (ft)	Cap Material	Year Constructed	Performance	Comments
PAH, NAPL, and Creosote-contaminated Sites							
Pacific Sound Resources, Seattle, WA	Polycyclic aromatic hydrocarbons (PAHs), nonaqueous-phase liquid (NAPL), mercury	58-acre cap	2.5–6	Cap material was partly from upland quarry (287,000 yd^3) and partly beneficial reuse of sand from navigational dredging (230,000 yd^3).	2003–2005	No observed migration of contaminants based upon pore-water sampling in 2010.	Upland borrow-material met grain size specifications and organic content requirements. Site included a steeply sloping (50%) offshore area and deep (-240 ft) water capping with dredged material.
Head of Thea Foss Waterway, Tacoma, WA	PAHs, NAPL	21 acres	3	Composite cap included sand, high-density polyethylene (HDPE), and armoring.	2003	• Cap recontaminated • Appeared to be upstream source control issue	Engineered cap included partial dredging to increase depth, placement of HDPE to control ebullition of NAPL, armoring as scour protection near stormwater outfalls.

Table 5-3. Representative contaminated sediment capping projects (continued)

Project	Contaminants	Site Conditions	Design Thickness (ft)	Cap Material	Year Constructed	Performance	Comments
Wyckoff-Eagle Harbor, Bainbridge Island, WA	PAHs, creosote, NAPL	East and West Eagle Harbor total cap of 70 acres	1–3	Cap material was a beneficial reuse of sand from navigational dredging.	1994	• Cap contained contaminants • Cap erosion in ferry lane • Source control failures leading to recontamination • No evidence of migration based upon pore-water sampling in 2011 (Reible and Lu 2011)	Cap erosion measured within first year of monitoring, seen only in area proximal to heavily used Washington ferry lane. Contaminants also observed in sediment traps. Monitoring demonstrated long-term risk reduction through elimination of liver lesions in English Sole.
PAH, Mercury, Heavy Metal, and SVOC-contaminated Sites							
Wyckoff-Eagle Harbor, Bainbridge Island, WA	PAHs, mercury	East and West Eagle Harbor total cap of 70 acres	0.5-foot thin cap over 6 acres and 3-foot thick cap over 0.6 acre	22,600 tons of sand for thin cap and 7,400 tons of sand for thick cap	1997–partial dredge and cap		To date, post-verification surface sediment samples have met the cleanup criteria established for the project. Ongoing monitoring.

Table 5-3. Representative contaminated sediment capping projects (continued)

Project	Contaminants	Site Conditions	Design Thickness (ft)	Cap Material	Year Constructed	Performance	Comments
Pier 64, Seattle, WA	PAHs, heavy metals, phthalates, dibenzofuran	—	0.5–1.5	Cap material was a beneficial reuse of sand from navigational dredging.	1994		Thin-layer capping was used to enhance natural recovery and to reduce resuspension of contaminants during pile driving.
New Haven Harbor, CT	PAHs, metals	—	1.6	Silt	1993		Extensive coring study
Port Newark/ Elizabeth, NY	PAHs, metals	—	5.3	Sand	1993		Extensive coring study
Pier 53–55 CSO, Seattle, WA	PAHs, heavy metals	—	1.3–2.6	Cap material was a beneficial reuse of sand from navigational dredging.	1992		Pre-cap infaunal communities were destroyed in the rapid burial associated with cap construction.
GP Lagoon, Bellingham Bay, WA	Mercury	Shallow intertidal lagoon	3	Sand	2001	• No contaminant migration at 3 months • Cap successfully placed	Ongoing monitoring
Experimental Mud Dam, NY	PAHs, metals	—	3.3	Sand	1983		Cores collected in 1990

Table 5-3. Representative contaminated sediment capping projects (continued)

Project	Contaminants	Site Conditions	Design Thickness (ft)	Cap Material	Year Constructed	Performance	Comments
Mill-Quinnipiac River, CT	PAHs, metals	—	1.6	Silt	1981		Cores collected in 1991
Norwalk, CT	PAHs, metals	—	1.6	Silt	1981		Routine monitoring
Stamford-New Haven, CT	PAHs, metals	—	1.6	Sand	1978		Cores collected in 1990
GP Lagoon, Bellingham, WA	Mercury	Shallow intertidal lagoon	3	Sand	2001	• No contaminant migration at 3 months • Cap successfully placed	Ongoing monitoring
Central Long Island Sound Disposal Site, NY	Multiple harbor sources	—	Unknown	Sand	1979–1983	• Some cores, uniform structure with low-level contaminants • Some cores, no contaminant migration • Some slumping	Extensive coring study at multiple mounds showed cap stable at many locations. Poor recolonization in many areas.
New York Mud Dump Disposal Site, NY	Metals from multiple harbor sources	—	Unknown	12 million yd^3 of sand	1980		Cores taken 3.5 years later in 1983 showed cap integrity over relocated sediments in 80 ft of water.

Table 5-3. Representative contaminated sediment capping projects (continued)

Project	Contaminants	Site Conditions	Design Thickness (ft)	Cap Material	Year Constructed	Performance	Comments
Duwamish Waterway/ Diagonal CSO, Seattle, WA	PCB, phthalates, mercury	7 acres placed on cut-slope	Cap placed over slope on cut-in benches. 3-5 ft	Composite cap included sand for isolation, cobble to rip-rap for erosion control, and habitat material (fish mix).	2003–2004		Armoring for erosion control was required for most of the site. The habitat enhancement layer was placed over areas shallower than -10 ft mean lower low water (MLLW).
Hylebos Waterway, Commencement Bay, WA	PCBs, mercury, semi-volatile organic compounds (SVOCs)	800 ft long by 20–25 ft wide	Cap placed over 2:1 cut slope to a total thickness of 3.5 ft	Heavy non-woven geotextile base layer, 1.5 ft of quarry spalls and 2 ft of pit-run compacted sand/ gravel.	2004		Intertidal cap was placed using conventional upland equipment during low tide sequences. Tidal elevations were between +12 and 0 MLLW.

Table 5-3. Representative contaminated sediment capping projects (continued)

Project	Contaminants	Site Conditions	Design Thickness (ft)	Cap Material	Year Constructed	Performance	Comments
Olympic View Resource Area, WA	PCBs, dioxins	1.3-acre cap	Variable, depending upon cap area (intertidal, subtidal, habitat)	Sand, granular AC (GAC) and river rock	2002		Intertidal – 11,438 tons removal with 14,500 tons of backfill sand. Contaminated subtidal area was capped with approximately 9,000 tons of sand cap material placed from a barge-mounted tremie tube. In some areas, GAC was mixed at 4% by volume (1.5% by weight) as a precautionary barrier.
Convair Lagoon, San Diego, CA	PCBs	5.7-acre cap in 10-acre site; water depth 10–18 ft	2 ft of sand over 1 ft of rock	Sand over crushed rock	1998		Ongoing monitoring for 20–50 years, including diver inspection, cap coring, biological monitoring

Table 5-3. Representative contaminated sediment capping projects (continued)

Project	Contaminants	Site Conditions	Design Thickness (ft)	Cap Material	Year Constructed	Performance	Comments
Note: Information in this table, particularly in the *Performance* column, is based on the last monitoring event. The amount of available data on these projects varies widely, monitoring data for many of the sites are limited, and some of the sites have not been monitored for several years. Table based on the following sources: • Sumeri, A. 1984. "Capped In-water Disposal of Contaminated Dredged Material: Duwamish Water Site." In R.L. Montgomery and J.W. Leach (Eds.), Dredging and Dredged Material Disposal, Volume 2. Proceedings of the Conference Dredging '84, November 14–16, 1984, Clearwater Beach, FL, American Society of Civil Engineers, NY. • RETEC. 2003. Feasibility Study for the Lower Fox River and Green Bay, Appendix C. Prepared for the Wisconsin Department of Natural Resources, Madison, Wisconsin. • Truitt, C.L. 1986. The Duwamish Waterway Capping Demonstration Project: Engineering Analysis and Results of Physical Monitoring, Final Report. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS, Technical Report D-86-2, March. • USEPA. 1998. Manistique River/Harbor AOC Draft Responsiveness Summary, Section 4: In-place Containment at Other Sites. USEPA Region 5 and Wisconsin Department of Natural Resources (September 25). • The Johnson Company, 2002. Draft Summary of Contaminated Sediment Capping Projects. http://johnsonco.com/pcb-contaminated-sediment/							

Table 5-4. Representative active sediment capping projects

Sediment Project	Contaminants	Site Conditions	Design Thickness (feet)	Cap Material	Year	Performance
Permeability Control Projects						
Ottawa River, OH	Metals, PCBs	107,000 ft^2	0.5-0.6 ft	AquaBlok	1999	Placement by conveyor, clamshell, and helicopter was demonstrated.
Galaxy/Spectron Little Elk Creek, MD	VOCs, DNAPL	63,000 ft^2	0.7 ft	Bentomat CL	1999	Groundwater pumping capacity was increased to reduce hydrostatic pressure on cap. Monitoring has shown upgraded hydraulic control and cap to be effective.
Anacostia River	PAHs, metals and PCBs	Low flow river, 1 acre site (10,000 ft^2 for permeability control)	0.5 ft +0.5 ft sand	AquaBlok	2004	Effective placement via clamshell. Reduction of upwelling in AquaBlok capped area, diversion of groundwater further offshore. Gas ebullition led to uplift and deterioration of containment in one area.
Tennessee Products, Chattanooga Creek, TN	PAHs	175,000 ft^2	0.5 ft	AquaBlok	2007	Containing mobile NAPL. Monitoring via pore water showing good containment in 2010-2012.
Penobscot River, ME	PAHs (MGP site)	High flow High tidal river 60,000 ft^2		AquaBlok	2010	Designed to eliminate gas ebullition through NAPL, channel gas/NAPL away from river. Monitoring is ongoing.

Table 5-4. Representative active sediment capping projects (continued)

Sediment Project	Contaminants	Site Conditions	Design Thickness (feet)	Cap Material	Year	Performance
Sorbing Amendments (Contaminant Migration Control) Projects						
Anacostia River	PAHs, metals and PCBs	Low flow river, 1 acre site (10,000 ft^2 for permeability control)	1) Reactive Core Mat +0.5 ft sand 0.5 ft 2) Apatite+0.5 ft sand	Coke in Reactive Core Mat, Apatite	2003	Placement of Reactive Core Mat and thin layers of bulk material was achieved, and the effect of recontamination from storm drains was monitored (Reible et al. 2006). Long-term monitoring via passive sampling results (Lampert, Lu, and Reible 2013).
McCormick and Baxter Superfund Site, Willamette River, OR	Creosote, NAPL	23 acres	2	Composite cap of organoclay, sand, armoring, and habitat mix. Also organoclay in mats in gas area	2004	No observed contaminant migration based upon pore-water sampling over 5 years and other sampling efforts. The project was completed in 2004; short-term data show cap remains effective; sheens initially observed have been determined to be biological in origin.
Stryker Bay, Duluth MN	PAHs	1,000,000 ft^2	Reactive Core Mat (<1") overlain by sand	AC in Reactive Core Mat	2006, 2010	Excess cap layer built up to encourage consolidation. Retained contaminants during consolidation.
BROS, Logan Township NJ	PAHs	240,000 ft^2	Reactive Core Mat (<1")	Organoclay in Reactive Core Mat	2009 2010	Wetlands with intermittent inundation.

Table 5-4. Representative active sediment capping projects (continued)

Sediment Project	Contaminants	Site Conditions	Design Thickness (feet)	Cap Material	Year	Performance
Roxana Marsh, Grand Calumet IN	PAHs	980,000 ft^2	Intermixed with sand in 6" cap with overlying sand	Organo-clay	2011	Intermixed bulk placement in a slurry with sand. Monitoring is ongoing.
Onondaga Lake, Syracuse NY	VOCs, PAHs, metals	Freshwater lake 200 acres	AC Intermixed in cap	AC bulk placement	Initiated 2012	Demonstrated capability of placing AC in bulk in a mixture (perhaps most difficult amendment to place in this manner due to low density).

Table 5-5. Case studies describing conventional and amended capping experience

Case Study	Contaminant	Site Description	Amendment
Conventional Capping			
Wyckoff-Eagle Harbor, Bainbridge Island, WA	Creosote, PCP, PAHs, metals	Subtidal and intertidal areas	NA
Port of Tacoma Piers 24 and 25, WA	PCBs, PAHs, metals	Marine embayment	NA
Grasse River, NY	Metals, PCBs	River	NA
Bellingham Bay, WA	Hg, 4-methylphenol, phenol	Marine embayment	NA
Black Lagoon, Detroit River, MI	PCBs, metals	River lagoon	NA
Bremerton Naval Yard OU B, WA	PCBs, Hg	Marine embayment	NA
Callahan Mining, ME	PCBs, metals	Tidal estuary	NA
Hackensack River, NJ	Chromium	River	NA
Hooker Chemical, Niagara Falls, NY	PAHs	River	NA
Ketchikan Pulp, AK	Arsenic, metals, PCBs, ammonium compounds, 4 methylphenol, H_2S	Marine cove	NA
Koppers Site, Former Barge Canal, Charleston, SC	NAPL, Total PAH	Tidal and non-tidal wetlands, tributary and river	NA
Manistique River & Harbor, MI	PCBs	Tidal River	NA
McCormick & Baxter, CA	PAHs, Dioxins	Marsh, wetland, floodplain	NA
Metal Bank, PA	PCBs, SVOCs, Dioxins	Tidal river	NA
Torch Lake Superfund Site, MI	Metals, PAHs, PCBs, coal tars, Nitrates, ammonia compounds, contamination from explosives	Lake	NA

Table 5-5. Case studies describing conventional and amended capping experience (continued)

Case Study	Contaminant	Site Description	Amendment
Amended Capping			
Anacostia River	PAHs, metals	River	AquaBlok, Coke Reactive Core Mat, apatite, and sand
Aberdeen Proving Ground, MD	Chloroform, Carbon Tetrachloride, Tetracholorethene, Pentachloroethane	Tidal Wetland	Reactive Mat
Galaxy/Spectron Inc., Little Elk Creek, Elkton, MD	Chlorinated solvent DNAPL	Creek	Geosynthetic Clay Liner and Bentomat CL
Hudson River Poughkeepsie NY	Coal tar NAPL	Tidal river	Organophilic clay
Penobscot River, ME	Coal tar NAPL	River	Organophilic clay
Pine Street Canal, VT	PAHs, VOCs, Metals, Coal Tar	Canal	Reactive Core Mat containing organophilic clay
McCormick and Baxter Site, Portland, OR	PAHs	Slough	Sand
Port of Portland	Metals, pesticides, PCBs, petroleum products,		Organophilic clay
Stryker Bay, Duluth, MN	PAHs, metals, coal tar	Lake Bay	AC Reactive Core Mat
West Branch Grand Calumet River, Hammond, IN	PAHs, PCBs, metals, coal tar NAPL.	River	Organophilic clay
Zidell- Willamette River, OR	PCBs, metals, PAHs, TBT	River	Organic carbon

6.0 REMOVAL BY DREDGING AND EXCAVATION

Dredging or excavation remedies remove contaminated sediment from freshwater or marine water bodies in order to reduce risks to human health and the environment. Removal is particularly effective for source control (mass removal of hot spots) but potentially less effective for overall risk reduction because of resuspension and residual contamination. Incorporating design features for resuspension control and residuals management can further reduce risk. After removal, the contaminated sediment can be treated or disposed in a controlled setting, such as an off-site landfill or other treatment, storage, and disposal (TSD) facility, an on-site aquatic or terrestrial confined disposal facility (CDF), or a facility that converts the sediment to a reusable product.

Under favorable circumstances, sediment removal can be effective in achieving RAOs, as illustrated in the case studies in Appendix A, which are summarized in Section 6.7. Removal has the potential, however, to disrupt the sediment and aquatic environment in the short term. Removing contaminated sediment can liberate a significant quantity of contaminants and leave residuals that may pose significant risks. Removal implementation costs are often higher than costs of other technologies, thus the selection process for this approach must balance costs, the site characteristics that drive applicability and limitations, and the net risk reduction that this approach can achieve. With a thorough site characterization, some of the removal challenges can be addressed through design and by using best management practices (BMPs) during operation.

6.1 Removal by Dredging and Excavation Background Information

Dredging of harbors and rivers for navigational purposes has been practiced for centuries and studied extensively. By comparison, environmental dredging (dredging for the sole purpose of removing contaminated sediment) is a relatively new development. While navigational dredging experience can be applied to environmental dredging projects, these applications have several key differences. For example, navigational and environmental dredging differ in their respective production rates (the amount of material dredged per hour). In navigational dredging, the production rate determines dredging effectiveness—a higher production rate results in a more successful project. In environmental dredging, production rate can affect the cost of the project, but not necessarily the success of the project. For environmental dredging operations, the removal operation is highly controlled, with efforts focused on minimizing the removal of clean material while, at the same time, controlling contaminant residuals and limiting the spread of contaminants. This level of control is often achieved at the cost of production rate. For an environmental project, remedial objectives can still be met despite a low production rate. Additionally, the controlled dredging needed for environmental projects results in a more resource-intensive operation than navigational dredging.

6.2 Dredging and Excavation Objectives and Approaches

The two primary methods of contaminated sediment removal are mechanical dredging and hydraulic dredging. A third method, excavation, is also described because it has been used at a number of sites in recent years. Dredging and excavation inevitably affect the aquatic and benthic environments, and this chapter presents some ways to minimize these effects. As with any type of removal operation, additional technologies are required to appropriately handle the removed sediment. Dredged material handling technologies may involve transport, dewatering, treatment, and or disposal of sediment.

6.2.1 Mechanical Dredging

Mechanical dredging removes sediment by capturing the sediment and then lifting the captured material to the surface. The dredged material is removed at near in situ solids content and density. A mechanical dredge usually consists of the following:

- a bucket equipped with a cutting and grabbing edge
- a crane or other means of lowering, manipulating, and retrieving the bucket (with the dredge material) through the water column
- a means of transporting (usually a barge) the dredged material from the dredging site to a sediment handling and processing or disposal facility

Equipment typically used for environmental dredging includes environmental clamshell buckets or enclosed clamshell buckets. More detailed descriptions of each mechanical dredge types can be found in Section 5.1 of the USACE's technical guidelines for dredging (2008).

Depending on site conditions, mechanical dredging equipment can sometimes be operated from shore; however, most dredges are set up on a barge (floating platform) equipped with an anchoring system, such as spuds, to hold it in place. Dredged sediment from near-shore locations can sometimes be transferred to shore by the same mechanical dredge and barge. If the dredging site is further from shore, the dredged sediment may be transferred to a second barge that hauls the sediment to the handling and disposal facility. Access to shore-side facilities or infrastructure is often used to provide an off-loading area or staging area for treatment or dewatering of the dredged sediment.

6.2.2 Hydraulic Dredging

Hydraulic dredging operations remove sediment by fluidizing and pumping the material to the handling location. A hydraulic dredge usually consists of a dredge head and a hydraulic pump. The dredge head is lowered into the sediment bed to fluidize the sediment by mechanical agitation and to draw the slurry into the suction pipe. Cutter heads and horizontal augers are the most common forms of dredge head design for environmental dredging. The hydraulic pump may be deck mounted or submersible.

Additional equipment needed for hydraulic dredging includes a ladder or cable used to support the dredge head and lower it into the water, as well as to swing the dredge head to advance into the sediment face. Most hydraulic dredges use spuds, which are devices driven into the sediment to stabilize the discharge line and the dredge, as they are operated or maneuvered using a cable system. A number of specialty hydraulic dredges are also available, including purely suction devices often used to dredge residuals or fluid sediments. These specialty dredges can also use water jets or pneumatic methods to fluidize the sediment, but these approaches are less common. Hydraulic dredges without mechanical agitators for fluidization are called "plain suction" dredges. A vacuum hose without an agitator can be used for dredging loose sediment at some sites. This operation is usually assisted by divers who guide the hose around obstacles.

Because the sediment must be fluidized and pumped, large volumes of water are mixed and transported with the sediment, resulting in the recovery of a slurry that is typically composed of between 10–15% (by weight) solids but may contain as little as 1–2% solids. The volume of water added to create a slurry that can be pumped (referred to as carrier water) depends on the in situ solids content of the sediment, sediment grain size, and pumping distance. For environmental dredging projects, the volume of carrier water needed is typically 5–10 times the in situ volume of sediment, which equates to 1,000–2,000 gallons per in situ cubic yard.

Hydraulic dredging is described in more detail in USEPA's sediment guidance (USEPA 2005a) and in the USACE technical guidance (2008). When applicable, hydraulic dredging is economical for removing large volumes of sediment and is used in both navigational and environmental dredging.

6.2.3 Excavation

Excavation refers to sediment removal conducted after the water above the sediment has been removed. In an excavation remedy, operators isolate a segment of the sediment and water column in an enclosure, dewater the enclosure, and remove the exposed sediment using conventional land-based excavation equipment. To isolate an area for dewatering, containment structures such as cofferdams, earthen berms and sheet piles are first installed to seal off the area and encircle the contaminated sediments. Once isolated, the interior of the enclosure can be pumped to remove water prior to sediment removal. Excavation equipment is often similar to that used in mechanical dredging and includes excavators, backhoes, and clamshells. In areas with large tidal swings, significant seasonal tidal changes, or intermittent streams and wetlands, excavation can be performed during low-water conditions and sometimes without an enclosure.

Excavated sediment usually contains less water than dredged sediment and thus is easier to handle. Excavated sediment, however, may still require additional land-based dewatering or solidification followed by off-site transport and disposal. In general, improved access to target dredging areas, greater control on dredge cuts, reduced concerns regarding resuspension of residuals, and potentially reduced sediment dewatering needs are the primary factors for selecting removal by excavation rather than by dredging.

6.3 Design Considerations

The most significant advances in environmental dredging in recent years have been the result of improved planning and operational efficiency, rather than the result of improved technology. Some conventional navigational dredging equipment has been customized to meet specific needs at larger sites. Enhanced planning and operational procedures, however, have been shown to improve removal efficiency and reduce the resuspension of sediment and generation of residuals for sites of any size. Residuals and resuspension are significant technical, environmental, and economic considerations for dredging (see Section 6.3.5). Reducing residuals and resuspension improves the overall effectiveness of removal and excavation technologies.

6.3.1 Removal Planning

During removal planning, surface-weighted average concentrations (SWAC) may be used as targets to be met during dredging. In this method, a site is divided into cells (or "bands") of varying contaminant concentrations. Cells are removed by dredging or excavation to meet a site-wide SWAC that is below the remediation goal. Often, the highest concentration cells are targeted for removal first because remediating these cells significantly reduces the SWAC.

The SWAC approach has proven effective as a target in field applications. At several recent mechanical and hydraulic dredging sites, dredging targeted sediments that were causing an exceedance of a SWAC equal to the cleanup goal. In a recent five-year review at the Continental Steel site at Kokomo and Wildcat Creek, USEPA Region 5 and the Indiana Department of Environmental Management (IDEM) affirmed that the SWAC approach is more representative of the exposure domain for receptor populations than the small areas represented by individual samples (IDEM 2007). At the Army's Natick site at Pegan Cove, the site achieved no further action (NFA) status after hydraulic dredging was conducted to achieve a cove-wide SWAC below the risk-based remediation goal of 1 ppm of PCBs. Backfilling was used in some areas with persistent residuals. At very large sites, such as New Bedford Harbor, SWAC goals are being assessed on different reaches of the river or harbor.

When low concentration goals are established for a site targeted for removal, residuals and resuspension or deposition may affect the attainment of these remedial goals. At a number of dredging sites, multiple dredging passes have been required to remove the residuals deposited and, in some cases, capping has ultimately been required to achieve the remediation goal. At the GM Massena site (St. Lawrence River, NY), following more than 15 dredge passes, backfilling of dredged areas with clean material was required to achieve 1 ppm of PCBs in portions of the dredge prism. Consequently, residuals management plans are now being developed along with the removal plan in order to optimize the number of dredging passes and reduce resuspension, contaminant release, and erosion of residuals.

In planning for removal of contaminated sediments, site project managers must also consider biological factors. Fish reproduction or benthic community survival windows often permit removal only during certain times of the year (referred to as "dredging windows"). Additionally, benthic community structure may restrict the times during which removal can occur. While dredging does not usually damage fisheries, the effects of removal on the benthic community must be evaluated during planning. Additionally, the upland habitat of endangered species or sensitive wetlands habitat may be affected by sediment removal operations. Site evaluations must consider potential risks to these habitats when selecting access sites, lay-down areas, staging areas, and transfer areas.

6.3.2 Removal Operations

Recent advances in dredge positioning and stability have improved the accuracy of environmental dredging. The accuracy of both mechanical and hydraulic dredges is affected by many of the same factors, such as wind speed (especially for an unanchored platform), currents, positioning system accuracy, and operator skill. A positioning system accuracy of ±1 corresponds to a mechanical bucket cut, or the arc of a hydraulic dredge cut, accuracy of ±1. At many sites, dredge operators have addressed accuracy limitations by over dredging (overlapping cuts). Over dredging materials, however, can become significant where the processing and disposal costs for removed sediments are high. For example, site managers who try to address a positioning accuracy of ±1 ft with a minimal overlap of 6 inches must target a mapped overlap of as much as 2.5 ft. The USACE guideline (2008) contains a more detailed discussion of vertical and horizontal dredging accuracy.

Although sophisticated positioning systems have been used at a few large sites, such as Fox River and Green Bay, at many moderately-sized sites, project teams have tried to incorporate some version of advanced positioning into dredging operations. Over-dredging usually proves to be an easier method to reach target depths and remove sufficient sediment. Bathymetric measurements before and after dredging are typically used to verify that target depths have been reached. This conventional method is seemingly crude but effective; however, as much as 20–25% more sediment than targeted may be dredged.

Several recent advances in dredging operations have improved targeted removal operations (Pastor 2012). One advanced positioning system, real-time kinematic global positioning, allows dredging to be focused on specific areas and depths, thus minimizing the requirement for over-dredging to achieve design goals. At some sites, this advanced positioning system can be an alternative to over dredging and its associated increased costs and materials handling. Finally, operator training and experience are other important variables in sediment removal that affect removal success (Pastor 2012).

Advanced Operational Controls

At the Fox River and Green Bay sites in Wisconsin, real-time kinematic global positioning system (RTK GPS) was used. A state-of-the art technology, RTK GPS indicates to the operator exactly where the dredge head is located while it is underwater (Pastor 2012). For each cut, the dredge is positioned in the water using RTK GPS and a series of electronic sensors measure tilt angle, acceleration, shock, vibration, and movement. The position of the cutter head is tracked and recorded in relation to the dredge. Special software uses input from the GPS and sensors to show the operator the exact position of the cutter head. The RTK GPS has been used at this site since 2004 and has improved the accuracy of dredging.

RTK GPS was developed specifically for this site. The technology cost several hundred thousand dollars, but it is expected to save money and time through improved efficiency. This system targets the neat line, a location identified during sediment characterization as the depth where PCB levels in the sediment drop from over 1 ppm to under 1 ppm (the target cleanup level). Before RTK GPS, the dredging plan was implemented using operator judgment. The operator reviewed the site map and make multiple dredging passes, often dredging more than was necessary.

A similar targeting system was also used at Ohio's Ashtabula River. Although the RTK GPS was developed to work with hydraulic dredges, a similar system has been used in other places, such as Commencement Bay in Washington, with a clamshell dredge. According to USEPA staff, this system has not yet become standardized because of high development costs. In addition, the different sediment types (such as mud versus sand) and varying conditions and accessibility at different sites have also slowed the development of a standard system.

6.3.3 Mechanical Dredging Design

Conventional mechanical dredging equipment, such as dredges that use a clamshell bucket, bucket ladder, or dipper and dragline, are ineffective for environmental dredging. A variation of the conventional clamshell bucket, the enclosed dredge bucket, has been developed to limit spills and leaks from the bucket. An enclosed bucket reduces resuspension by improving the seal between the elements of a closed bucket. An enclosed bucket also reduces releases of water-soluble contaminants into the water column during dredging. Additional modifications to conventional mechanical dredging equipment based on site-specific conditions include:

- fitting the crane with longer boom (arm) for additional reach during dredging
- fitting an excavator with a longer arm for better access

- using a fixed arm bucket instead of a cable suspended bucket to increase the accuracy and precision of cuts and to provide greater bucket penetration in stiffer materials
- equipping the bucket with hydraulically operated closure arms to reduce bucket leakage
- installing a sediment dewatering and water collection and treatment facility on the barge or at a temporary staging site
- installing GPS and bucket monitoring equipment to the dredge to provide the equipment operator with precise coordinate control of the bucket during dredging operations

Often, backhoes can be modified or equipped with covers for the bucket to improve retention of the sediment and to minimize resuspension. Clamshell dredge buckets can also be fitted with baffles and seals to slow the movement of water and mud. USACE used this type of seal, which is similar to a rubber gasket, at the Fox River and Green Bay sites to minimize leakage of PCB-contaminated water and sediment from the bucket.

6.3.4 Hydraulic Dredging Design

Recent developments in hydraulic dredging equipment have typically included project or site-specific modifications in order to achieve the following objectives:

- Increase solids content in the dredged material and lower water content.
- Prevent debris from entering the auger or pump intake.
- Pump dredged material over greater heights or distances.
- Improve on shore dewatering of dredged material.
- Reduce potential for releasing dredged sediment into the water column.

Because site conditions can vary greatly, many of these equipment and other modifications are not considered standard practice. For example, a screen that is installed on a hydraulic dredge to prevent debris from entering the auger or pump intake could also slow down production at a given site by reducing the sediment flow rate in the pump.

6.3.5 Resuspension and Residuals

In evaluating, selecting, and designing a removal remedy, the effects of removal (particularly dredging) must be taken into account. Contaminated sediment removal actions resuspend sediment, generate residuals, and release contaminants as follows (USACE 2008):

- *Resuspension* is the fluidization and dispersion of the sediment particles into the water column due to dredging and associated operations. Resuspended sediment may eventually settle out in dredged areas or disperse and settle in surrounding areas.
- *Residual* is the disturbed, or undisturbed, sediment that remains in the dredged area (or local vicinity) following a dredging operation.
- *Releases of contaminants* from the sediment bed may occur due to dredging, and from the same processes that generate resuspension and residuals. Releases, however, may also

include loss of pore water, NAPL (if present), and associated contaminants. Releases may further occur from the desorption of contaminants from resuspended sediment and residuals.

The potential risk reduction from the removal of contaminated sediment must be weighed against these potential increased risks from contaminant releases due to dredging.

Dredging-related resuspension, residuals, and releases can lead to increases in contaminant levels in fish tissue, difficulty in achieving sediment-based cleanup goals, and the need for additional postdredging site management or residuals management. The risk profile of a site can change following a dredging operation. While risk is potentially reduced by the removal of contaminants associated with the dredged material, residual risk may remain (and may need to be addressed) at the dredged site due to resuspension, residuals formation, or releases.

6.3.5.1 Resuspension

The degree of resuspension of sediment during dredging is determined by a number of factors, including:

- Sediment properties such as particle size, cohesiveness, and bulk density can affect resuspension. Silts are more easily resuspended than sands (which are larger and heavier than silt) and clays (which are smaller, but tend to be more cohesive or plastic than silts).
- Site conditions such as water depth, current velocity, waves, and underlying bedrock can make operational control difficult.
- Impediments such as debris, boulders, and pilings associated with piers can affect the operation of the dredge and lead to sub-optimal operating conditions.
- Operational factors such as design and planning of the dredge cuts, dredging equipment type, and operator skill can also influence resuspension.

Because these factors vary from site to site, a wide range of field data on levels of resuspension has been reported, ranging from less than 0.1% to as high as 5% (without losses from barges or hoppers). Resuspension rates from mechanical clamshell dredging operations typically range from 0.3 to 1.0% while losses from open bucket excavators tend to be as much as three times higher. Resuspension rates from hydraulic cutterhead dredging operations typically range from 0.1 to 0.6%, while losses from horizontal auger dredges tend to be about three times as high (USACE 2008). Characteristic (median) resuspension factors for hydraulic cutterhead dredges and closed mechanical environmental clamshell buckets are both estimated to be 0.5%, while resuspension factors for horizontal auger dredges and open buckets and excavators are two to three times higher (USACE 2008).

The performance of dredging equipment depends, in part, on sediment properties. Mechanical dredges limit resuspension of fines and contaminants from sandy sediments, while cutterhead and plain suction dredges limit resuspension of very soft, fluid sediments. Resuspension rates are based on navigational dredging and reflect the mass of fine particulates resuspended as a percentage of the fine-grained mass dredged, not the mass of contaminants adhering to or released with the sediment particles. Even in a well-managed operation, these suggested percentages may increase by a factor of two or three, depending on the presence of debris, debris removal operations, barge transport (tug operation), or any disturbance due to engineered controls such as silt curtains or sheet piling (USACE 2008).

Prediction models are available that can help designers estimate how much resuspension might occur and then plan for residuals. Risks and the need for engineering controls should also be considered during planning stages. A number of prediction models are available that are based on navigational dredging experience (USACE 2008; Bridges et al. 2008; and USEPA 2005a). These models, however, use variables that are not easily measured or estimated at many sites. In addition, factors such as operator experience or ability to maneuver the dredge around impediments may also make model predictions unreliable.

Despite their limitations, prediction models provide insight on the potential for resuspension and can guide the selection of site-specific BMPs and controls. BMPs may include operational controls, engineering controls, or both. Engineering controls should be carefully evaluated because these controls tend to be relatively expensive and may generate some resuspension during installation and removal. These controls may also result in other unintended consequences such as channel restrictions that cause resuspension of nontarget sediment, air releases, DO consumption and fish kills, or exacerbated residuals.

When contaminant concentrations are high or when sensitive aquatic environments are present, engineering controls can be used to minimize the effects of sediment removal. The most common engineering control used in navigational and environmental dredging operations is the silt or turbidity curtain. Silt curtains are vertical, flexible barriers that hang from floats at the water surface. Silt curtains are generally deployed from the water surface to a depth of one to two feet above the sediment bed; the curtain is not a complete enclosure. The resulting height of the deployed curtain is called the skirt depth. The curtain material is held in place by floats on top and a ballast chain at the bottom. Anchored lines are attached to hold the curtain in place. For navigational dredging, silt curtains are considered a BMP and are often successful in controlling turbidity in the surrounding water column.

Silt Curtains

USEPA (1994) and ERDC (2005) consider silt curtains ineffective at depths greater than 20 ft and at current velocities greater than 50 cm/sec (approx. 1 knot). Under these conditions, silt curtains can be reinforced to some extent with sheet piling at the corners or additional anchoring measures, but the effectiveness of any additional measures should be verified in the field. Adding sheet piling considerably increases the cost of the application.

A study conducted as part of USEPA's Assessment and Remediation of Contaminated Sediments (ARCS) Program concluded that silt curtains are most effective at relatively shallow sites in relatively quiescent water and wind conditions (USEPA 1994). Silt curtains should not be used at depths greater than 20 ft, where the water column pressure on the mooring system becomes excessive, and at current velocities greater than 50 cm/sec (approximately 1 knot), where billowing or flaring of the curtain in the flow direction may reduce its effectiveness (USEPA 1994; ERDC 2005). High currents lead to flaring, which can cause the bottom of the curtain to be raised several feet above the sediment bed (and above the installed lower depth). High currents can also cause curtains to tear.

A summary of case studies that address resuspension is included in Section 6.7. As shown in Table 6-2, silt curtain resuspension controls were used at all sites where mechanical dredging was done under a column of water. Excavation was generally done in a sheet piling enclosure. Some success with silt curtains was noted at the Kokomo Creek site, where mechanical dredging was conducted along a two-mile stretch of a creek in water depths of 1–4 ft. Problems were reported with silt curtains at the Formosa Plastics site, where mechanical dredging was done in 25–30 ft of water. At this site, soft, silty sediment kept flowing into dredged areas from under the curtain.

As shown in Table 6-2, resuspension controls (generally silt curtains) were used at most sites with hydraulic dredging. Success appears mixed. Among the hydraulic dredging sites examined, Pegan Cove (water depth of 0–10 ft) reported success in using double silt curtains to successfully keep turbidity out of the surrounding water. At the New Bedford Harbor site (hydraulic dredging, in the Lower Harbor) use of silt curtains was abandoned after the curtains were found to contribute to scouring from high current velocities and turbulence. Difficulties were encountered in water depths of more than 20 ft. This site is now relying on BMPs (operational controls) to minimize resuspension to the largest extent possible. At the Waukegan Harbor site (hydraulic dredging), water depth was 25 ft in some areas, and silt curtains failed due to wind and wind-induced currents. Shallower sites encountered some problems as well; at the Lavaca Bay site, for example, elevated contaminant levels occurred downstream of silt curtains.

For some sites, silt curtains must be supplemented or replaced with other engineering controls. At the Fox River and Green Bay Project 1 site, silt curtains were reinforced with sheet piling at the corners to avoid frequent maintenance. At the GM Massena St. Lawrence River site, silt curtains did not contain turbidity and were replaced with interlocking sheet piling. Sheet piling provides better containment, but tends to prevent both water and suspended particles from moving into and out of the enclosure. Sheet piling enclosures should be monitored to confirm that dissolved oxygen in the enclosure does not get depleted. Note that sheet piling has a much higher installation cost when compared to silt curtains. At some sites, sheet piling was used to shore up the banks of the water body being dredged, rather than as an alternative for silt curtains. For excavation sites, cofferdams and removable dams are generally used for containment.

Oil booms are also sometimes used as an engineering control for sediments that are likely to release oils when disturbed. These booms typically consist of a series of synthetic foam floats encased in fabric and connected with a cable or chains. Oil booms may be supplemented with oil absorbent materials (such as polypropylene mats). These barriers are also effective for contaminants such as NAPLs, which can be readily released into the water column during removal.

6.3.5.2 Residuals

No dredging operation removes all contamination, and contingencies for residual contamination must be addressed during design. The Reynolds site, for example, experienced particular difficulty with residuals, requiring multiple passes in several of the cells dredged. In some cells, the 1 ppm PCB cleanup goal could not be met, despite multiple passes. These cells were backfilled with clean material to meet cleanup goals.

Two types of residuals are expected at dredging sites:

- *Generated residuals* arise when sediment is disturbed by dredging, but is not collected by the dredge. Resuspension and subsequent settling of particles, sloughing along the sidewalls, and spillage from the dredge head, bucket, or clamshell are the primary causes of generated residuals
- *Undisturbed residuals* are contaminants that are neither disturbed nor collected by the dredge. Undisturbed residuals could arise from one or more of the following:
    - insufficient characterization (as might happen at a large site)
    - inadequate characterization of the depth of contamination (especially at sites with deep contamination or debris)
    - limits of characterization methods (averaging of contamination in long sampling tubes)
    - impediments (such as rock outcrops, boulders, debris, structures, pilings, or utilities)
    - inaccuracies or insufficient control and precision in positioning during dredge operation

Additional factors that can cause residuals include slope failures, bucket over-penetration and overfilling (due to insufficient control or overly aggressive production rates), underlying bedrock, or an uneven sediment bed. Methods and calculations are available to predict the level of residuals, but as with resuspension, many site-related and operational variables can make prediction difficult (USACE 2008). One study showed that at several sites with PCBs, a family of contaminants that adheres strongly to sediment particles, 5–9% of the original PCB mass remained as generated residuals (Patmont 2006). At the other sites in this study, where contaminants were more soluble, the generated residuals ranged from 2–4%. The level of these residuals is greater than the level of resuspension (0.5–1 %) expected at a typical site. These results may indicate that spillage and fallback from dredging, sloughing, and slumping are major sources of residuals, contributing more to generated residuals than resuspension does.

Controls for residuals include equipment controls, operational controls, and postdredging controls. Equipment controls are modifications of the dredging equipment. Operational controls are implemented during dredging as a means of reducing residuals to the minimum amount feasible. Operational controls discussed in Section 6.3.5.1 for reducing resuspension, such as control of dredge cuts and production rates, are also useful in reducing residuals. The effectiveness of these operational controls has not been well documented, but in theory they should reduce residuals.

> **Resuspension and Residuals**
>
> *Dredging generates resuspension and residuals. When postdredging residuals exceeded acceptable risk thresholds, sites have successfully used backfilling to efficiently achieve further risk reduction and cleanup goals.*

Postdredging controls manage residuals after they have occurred. Over-dredging and the use of cleanup passes are the most common operational controls for residuals. These measures assume that there are limits to operational controls (such as positioning or depth of each cut), so the sediment is dredged to a greater depth or over a larger area than is warranted by the site characterization. A cleanup pass, made after the original target is reached, may help to gather residuals that have already accumulated and to mix the residuals with underlying clean sediment. The residual sediment that remains in the dredged area, however, may not have the same physical characteristics as the native sediment. In mechanical dredging, for example, resuspended residuals may settle in the dredged area at a lower dry-bulk density than the native sediment and may be more prone to fluidization and resuspension in subsequent passes. In this case, other dredging equipment such as a hydraulic suction dredge may be used to conduct additional cleanup passes and capture fluidized residuals. Note that these additional passes add expenses for a second mobilization with different equipment and operation.

Over-dredging is relatively common at sites where remediation goals are based on achieving a final cleanup concentration of contaminants in the sediment. Additional cleanup passes after initial dredging to required depths, however, result in increased cost. At some mechanical dredging sites, more sediment is dredged than planned (see Table 6-2). The excess dredged sediment may be a result of multiple dredge events or several passes over a single dredge area because confirmation samples indicated that project cleanup goals had not been achieved.

The available case studies show mixed results for dredging performance and postdredging sediment concentrations. Several mechanical dredging sites achieved clear success in meeting postdredging cleanup goals without backfilling (including sites with water depth greater than 20 ft). About half of the sites examined required backfill with clean material after dredging to help meet cleanup goals. Among the hydraulically-dredged sites (Table 6-3), at Gill Creek and Pioneer Lake cleanup goals were met. At Pegan Cove, cleanup goals based on SWAC were met after backfilling with clean sand. At Fox River and Green Bay, Operable Unit 1, and at GM Massena, meeting cleanup goals with hydraulic dredging was difficult, and some areas were eventually backfilled. At the Fox River and Green Bay Project 2 site, cleanup goals were not achieved after multiple passes. In postdredging sediment samples, concentrations were higher than pre-dredging samples in the same areas. These differences may be due to resuspension (and resettling), sloughing, heterogeneity of the sediments, or exposure of deeper contamination.

Postdredging management options and controls can also include backfilling or MNR. MNR as part of a technology train in dredged areas requires collecting data to establish natural recovery trends. This data collection may not be possible at all sites (such as for sediment in an erosional environment). Backfilling with clean material, sometimes called a "residuals cover" is often the quickest route to achieving target cleanup goals and has been used at many sites.

Backfilling of dredged locations with clean off-site material provides a cover over contaminant residuals at the newly created sediment surface. Backfilling is often a last resort after multiple dredging passes fail to achieve cleanup goals. A more efficient approach is to incorporate backfilling in the initial design at sites where residuals are expected and could hamper site closure. In this approach, backfilling is performed immediately after dredging has been completed to the targeted depths (as verified by a bathymetric survey). In shallow water systems, backfilling is also commonly incorporated into the remedial design to return the bed elevation to its original condition to support habitat functions and bank stability. Table 6-2 and Table 6-3 summarize several sites that used backfilling to help achieve cleanup goals.

6.3.6 Releases

Resuspension of sediment results in some short-term release of contaminants to the dissolved phase in the water column through release of pore water and desorption from suspended sediment particles. Additional releases may occur by erosion of the residuals or diffusion, mixing, or advection from the residuals. The release of dissolved contaminants yields the greatest risk because the dissolved phase drives biological uptake and volatilization. The fraction of the contaminant present in the dissolved phase of the water column increases with time as the suspension disperses and the contaminant desorbs. Depending on the contaminant, desorption may take hours or days to occur; therefore, control of sediment resuspension and residuals helps in control of contaminant release for contaminants normally associated with sediments—such as PCBs and PAHs, which tend to remain tightly bound to fine-grained sediment particles. For other forms of contaminants, such as NAPL, releases from the sediment during dredging can float to the surface as a separate phase. Appropriate measures may be required to control releases not related to the resuspended sediment particles or residuals.

Releases can substantially affect remedial efforts. For example, at the Grasse River site, resuspension and releases led to PCB levels in fish tissue that were 20 to 50 times higher than before dredging. Elevated fish tissue levels continued for three years. At the Shiawassee River site, samples of water, clams, and fish showed elevated levels of PCBs at all locations in the dredging area and downgradient. In all three media, PCB levels remained elevated over the six months that these levels were studied (Bremle and Larsson 1998; Rice and White 1987).

6.3.7 Removed Sediment Handling

Management of sediment removed through dredging or excavation requires integration of the dredging technique with transportation, treatment, and final disposal or reuse of the dredged material in an approved location. Each of these steps influences available options for subsequent steps in the material handling chain. If any one of these critical steps is infeasible from a technical or cost standpoint, it may preclude dredging as a viable remediation strategy. During remedy selection, costs for multiple strategies for removed sediment handling should be reviewed as part of alternatives that include dredging or excavation. Removed sediment handling is often a sizable component of the total cost—often exceeding the cost of the in-water dredging. Table 6-4 lists the dredged material handling methods used at various sites. Reports prepared by USEPA (2005a) and

USACE (2003) provide further discussion of previously implemented treatment and disposal technologies for dredged sediment.

6.3.7.1 Dewatering

Dewatering may be necessary to prepare dredged materials for disposal. Dewatering reduces the water content and hence the volume and weight of the disposed sediment. If the material is to be reused or further treated, dewatering also leads to reduced transportation cost and improves handling properties. The nature and extent of dewatering needed depends on the sediment characteristics and the type of dredging, transport, and disposal methods planned for the removed material.

Staging for dewatering operations varies depending on the resources available near the dredging site. Passive dewatering requires sufficient space to store the sediment during the separation process. Also, if the goal is to return the carrier water to the source river water body, dewatering relatively close to the discharge point would minimize piping costs. During passive dewatering, carrier water is removed primarily by gravity separation and to a lesser extent by evaporation. The more thinly the sediment can be spread at the dewatering site, the more effective passive dewatering by evaporation will be. Passive dewatering typically occurs in a CDF. Many other types of holding facilities can also be used, such as tanks or lagoons (USEPA 1994). Geobags with chemical conditioning have been used at many sites for efficient gravity dewatering of large volumes of sediment in relatively small spaces.

During active mechanical dewatering, equipment or materials are used to apply external pressure and can sometimes achieve a solids content of up to 70% by weight. Typical equipment used includes plate-and-frame presses, which are effective but operate in batch mode, and belt filter presses, which may be less effective but can be operated continuously. Water removed during mechanical dewatering must also be addressed. If the removed water contains contaminants at concentrations below regulatory thresholds, then it may be ready for immediate use or disposal. Otherwise, the water may require capture and treatment prior to disposal.

6.3.7.2 Dredged Material Disposal Methods

Disposal of dredged or excavated sediment is the placement of materials into a controlled site or facility to permanently contain contaminants within the sediment. Management is achieved through the placement of materials into facilities such as sanitary landfills, hazardous material landfills, CDFs, or confined aquatic disposal (CAD) facilities. Table 6-3 shows that off-site landfilling has been the most common disposal method for dredged material. Off-site landfills are generally used for dredged material disposal when on-site disposal is not feasible or when off-site disposal is more cost effective.

Landfills have been used for sediment volumes of over a million cubic yards. Typically, some type of on-site or near-site disposal facility is used at sites where dredged material volumes greater than that 200,000 yd^3 are generated. Landfilling is also favored at smaller or moderately sized sites, where transportation is feasible. The associated hazards and cost of transporting and landfilling large volumes of sediment make this disposal method somewhat less desirable than other solutions. Other considerations, such as public and stakeholder acceptance, lack of access to suitable on-site land- or water-based disposal facilities, and proximity to an existing off-site landfill may support the landfilling option. The Fox River and Hudson River sites are two larger sites where the dredged material is being landfilled at commercial disposal facilities.

CDFs are constructed to isolate dredged sediment from the surrounding environment. CDFs can be located upland, near shore, or in the water (as an island). Material staging or a temporary CDF may be necessary for dewatering dredged sediment. USACE (2003) and USEPA (2005a) describe CDFs in further detail. CDFs represent a common disposal method and typically are built for larger volume sites (200,000 yd^3 or more of sediment).

The CAD method deposits dredged material within a nearby body of water. A pre-existing depression within the sediment surface is preferred, though one can be created if necessary. Dredged sediment is deposited in the depression and capped with clean material. This process carries with it the same risks associated with using capping as a remedy (see Chapter 5). The goal of moving the contaminated sediment to the aquatic disposal site is to reduce the risk of exposure to contaminated materials (USEPA 2005a). Some sites, such as New Bedford Harbor, are in the process of building CAD facilities. Ease of permitting and long-term management of the disposal site may be considerations in selecting this method, but this additional effort may be warranted for large sediment volumes.

6.3.7.3 Removed Sediment Treatment

Removed sediment is sometimes treated in order to facilitate reuse prior to aquatic or land disposal. Sediment is treated to meet disposal regulations, to reduce volume to be disposed of, or to facilitate beneficial use. On-site treatment is determined according to the planned subsequent use or off-site disposal method for the material. For a particular site, it may be more economical to treat dewatered sediment on site to stabilize heavy metals, and then transport the treated material to a Toxic Substances Control Act (TSCA) compliant landfill for disposal of PCBs. On-site treatment techniques may include dewatering and physical size separation, followed by bioremediation, chemical treatment, extraction/washing, solidification/stabilization, or thermal treatment (USEPA 2005a). Information regarding on-site treatment is also available from the *Federal Remedial Technologies Roundtable Technologies Screening Matrix and Reference Guide* (FRTR ver 4.0).

6.3.7.4 Removed Sediment Beneficial Reuse

If contamination levels, treatment methods, or economics permit, dredged or excavated sediment may be used for beneficial purposes (for example, as construction material for road building). As excavation plans are prepared, local needs should be reviewed and the beneficial use of excavated material should be considered. The potential for reuse of slightly contaminated or treated sediment is dependent upon the assurance that the planned use is protective of the environment and that future activities will not release unacceptable levels of contamination to the environment. The material can be reused either in aquatic or upland sites, depending upon the condition of the material and local needs. Further disposal costs can be avoided by not using a landfill, but additional treatment costs may be involved in making the material environmentally safe for the proposed use. Further information on reuse of sediment can be found in reports from USEPA (2005) and USACE (1987). Although many pilot studies have examined the beneficial use of removed sediment, few field studies are available.

Recently, the New Jersey Department of Transportation's (NJDOT) Office of Maritime Resources teamed with Rutgers University's Center for Advanced Infrastructure and Transportation (CAIT) to develop a comprehensive manual for integrating processed dredged material (PDM) into common construction applications (NJDOT 2013). This guide, *Processing and Beneficial Use of Fine-Grained Dredge Material: A Manual for Engineers*, covers research, development, and implementation of dredged material management techniques.

6.4 Data Needs for Removal Design

This section describes the physical characteristics, sediment characteristics, contaminant properties, and land and waterway use characteristics that should be considered when removal is evaluated as a remedial technology. Not all of these characteristics are critical for technology assessment at all sites; however, a thorough review of these characteristics will help to determine whether the removal is suitable for the site and which removal technologies will be most effective and implementable.

6.4.1 Physical Site Characteristics

Physical site characteristics can determine whether removal is used at a given site, as well as the site zones that may be most promising for removal. In addition, site characteristics may influence how removal can best be accomplished. Inadequate site and sediment characterization for environmental dredging can potentially result in delays, higher costs, unacceptable environmental impacts, and failure to meet cleanup levels and remediation goals.

The data collected must be adequate to either determine whether removal should be selected as a remedy or to design a removal remedy. The timing and staging of the site characterization can also affect results. For example, during the early stages of an RI, there is less certainty as to which of the detected chemicals are COCs that require remediation. Therefore, the scheduling of site characterization often must be adapted based upon new information. These results determine the nature and extent of sediment contamination, inform remedy selection, and support remedial design. At many sites, a multi-phased characterization effort beginning during the RI and continuing into the FS and remedial design stage may be appropriate. The characterization must collect adequate site data to support decisions required during critical stages of the remediation process.

6.4.1.1 Sediment Stability

Sediment stability is not critical in the evaluation of removal as a remedial approach. In areas where sediments are unstable, however, natural disturbances would likely lead to significantly increased contaminant mobility and risk. These areas, therefore, may be good candidates for an active remedy such as removal.

6.4.1.2 Sediment Deposition Rate

The net deposition rate is not a critical factor in selecting removal as a technology; however, zones with higher net deposition rates may provide adequate natural cover material for post-removal residual sediments. This process makes the installation of a residuals cover unnecessary, since deposition rates greater than 1 to 2 cm/yr provide a 10-cm cover in 5 to 10 years. Residuals cover or backfilling, described in Section 6.3.5.2, is often used at sites when sediment cleanup goals canot be met after a single or multiple passes with dredging equipment. Note that removal can result in creation of depressions in the sediment bed and therefore net deposition rates immediately following removal can be greater than rates prior to removal.

6.4.1.3 Erosional Potential of Bedded Sediments

Erosional potential is not critical in the selection of removal as a remedial technology. Zones where erosion of the sediment bed would likely increase contaminant mobility and risks may be good candidates for engineered containment or removal, as long as erosion of dredge residuals are not a concern. *Sediments with relatively low bulk density (less than roughly 0.7 gm/cm^3 or 44 lb/ft^3) or low cohesive strength have a greater potential for resuspension when disturbed during removal, resulting in generated residuals and releases (see Section 6.3.5.2 for more on magnitude of releases observed at completed projects), particularly at sites with high hydrodynamic shear stresses or steeper slopes.* The potential for resuspension, which is further discussed in Section 6.3.5.1, should be considered on a site-specific basis when evaluating mechanical and hydraulic dredging options.

6.4.1.4 Water Depth and Bathymetry

Site bathymetry, and water depth in particular, are important for evaluating a removal approach. Generally, removal becomes increasingly more challenging as water depth increases. *Removal experience to date has been limited to depths of about 50 ft or shallower; however, removal in water depths up to 75 ft is possible (for instance, using hydraulic dredge equipment with a ladder pump configuration or cable mounted buckets). Removal of contaminated sediment in water deeper than about 75 ft is generally impractical.*

Note that as water depth increases productivity can decrease, releases to the water column can increase, and the accuracy of removal can decrease. Physical isolation controls (for example, silt curtains or rigid containment such as interlocking sheet piling) also have practical depth limitations for installation and effective operation (generally limited to about 20 ft of water or less). Mechanical dredges using fixed arm buckets are generally limited to about 20 ft of water unless a long-stick arm is used, which reduces the capacity of the bucket. Alternatively, shallow water can also restrict access for hydraulic and mechanical dredges by not providing sufficient draft for the equipment being used. Water shallower than 3 to 4 ft may limit access and removal to form a channel may be needed to facilitate access. *Excavation is generally restricted to zones with shallow* *water depths (typically less than 10 ft) where the removal area can be isolated and dewatered (such as shoreline excavation or lower flow streams that can be bypassed).*

Areas to be dewatered generally must be small enough to accommodate the dewatering operations. Larger areas and deeper water zones may still be considered for excavation in certain circumstances, but special engineering considerations may be needed, which complicate implementation and increase construction duration and cost.

6.4.1.5 In-water and Shoreline Infrastructure

All infrastructure (bridges, pilings, piers, utilities and even shoreline structures) adjoining the removal areas must be evaluated for stability before, during, and after removal. An adequate factor of safety should be built into the assessment. Safety offsets (leaving a buffer between the infrastructure and the removal area) or stabilization measures are often specified to avoid disturbance to the structures. Sediment located under structures such as piers may make removal impractical. For example, hydraulic dredges have limited access, maneuverability, and functionality to set cables and anchors to work around structures. A crane with a cable-mounted bucket has height requirements that can limit access, while fixed arm buckets can provide better accuracy in bucket placement and have the ability to reach under some structures.

Excavation generally poses concerns for shoreline slope and structure stability. Greater concerns for infrastructure integrity arise for deeper excavations, and structures and underwater utilities may limit effective containment, isolation, and dewatering of the removal area. In some cases removal and relocation of infrastructure may accommodate sediment removal, but in other cases moving the infrastructure may not be practical and may preclude sediment removal.

6.4.1.6 Presence of Hard Bottom and Debris

The presence of a hard bottom can limit effective containment during removal (if sheet piling is contemplated), depending on the composition and configuration of the hard bottom. Contaminated sediment overlying bedrock or glacial till may impede some dredging equipment. *Contaminated sediment lodged in crevices in bedrock can be impractical to remove.*

For hydraulic dredging, the presence of a hard bottom underlying the contaminated sediment limits over-dredging into a relatively clean surface and can also increase the magnitude of generated residuals and undisturbed residuals. For mechanical dredges, the presence of hard bottom typically leads to greater amounts of generated residuals and resuspension, due to over-dredging difficulties and the higher energy required to remove the consolidated underlying material. On the other hand, a hard bottom below contaminated sediment tends to limit over-excavation of material. *Attempting to re-dredge residuals on top of a hard bottom using either mechanical or hydraulic dredges has been shown to be less effective in reducing contaminant concentrations, but plain suction dredges can more effectively capture generated sediments and residuals from a hard bottom.* Mechanical leverage of an excavator during excavation results in more accurate removal and can remove hard material with less sediment loss.

Both large and small debris can slow some dredging equipment. Hydraulic dredges have inherent limits to the size of material that can be removed and are designed to only pass debris smaller than the diameter of the inlet pipe. As a result, a separate mechanical debris removal operation is often used to clear the area of large debris, logs, boulders, and cables prior to hydraulic dredging. Mechanical dredges are better suited to removing debris prior to sediment removal, but they also have some limitations depending on the specific equipment being used. For example, debris can become lodged in the bucket and allow sediment to discharge to the water body, thereby increasing turbidity. Special equipment may be needed to clear the debris. Debris removal activities, however, may disrupt the sediment structure and promote sediment erosion. *In general, the presence of debris tends to result in increased resuspension and generation of residuals and, consequently, reduced production. Zones with extensive debris make removal less effective, and in some cases may make removal impractical.*

Excavation techniques can generally accommodate debris removal without an increase in resuspension, release, and residuals.

6.4.1.7 Hydrodynamics

Hydrodynamic characteristics such as water velocities, water depth changes (tides) and waves can affect the performance of removal operations. Experience has shown that higher water velocities can increase the release and transport of contaminants due to resuspension (both initial resuspension as well as resuspension of generated residuals) and can also affect the implementability of resuspension control technologies. *Waves greater than 2 ft, currents greater than 1.5 fps, and fluctuating water levels greater than 3 ft complicate and may limit feasibility of removal and the effectiveness of more conventional resuspension controls like silt curtains.*

The use of rigid resuspension containment structures, such as sheet piling, can also cause secondary effects such as flood rise and create the potential for erosion due to channel conveyance constrictions. This effect may also arise adjacent to isolation systems used for excavation. Excavation can be designed to accommodate a range of hydrodynamic conditions to mitigate concerns for resuspension, erosion of residuals, and release of contaminants. The design should consider the potential for containment over-topping events and potential for releases, as well as effects on production rate.

6.4.1.8 Slope Stability

Sloping bathymetry of more than a few percent can affect removal operations. Each type of removal equipment has varying suitability to remove contaminated sediment on a slope. Navigational dredging equipment and operators are usually accustomed to performing removal operations to achieve a relatively flat bottom. Advances in equipment and operational procedures for environmental dredging, however, can now leave a more contoured bottom bathymetry after removal.

Steeper slopes can complicate dredging. These slopes are generally cut using a series of steps or box cuts progressing up the slope. These operations are less efficient and can result in greater removal of cleaner underlying sediments and slower production. A cut slope that is less than the angle of repose of the sediment promotes stability, because a higher angle may cause instability. For certain equipment, such as a cable mounted bucket and horizontal auger hydraulic dredges, slopes present difficulties in positioning and achieving a sloped cut elevation. Mechanical buckets mounted on a fixed arm operate much better on a slope but are typically limited to a water depth of about 20 to 25 ft. Since most mechanical equipment swings in an arc, improvements in slope dredging efficiency can be accomplished with the use of articulating buckets that better align with the slope. Some hydraulic operations rely on removal at the toe of slope to allow targeted sediment to fall or slide into the capture zone of the dredge. This operation can leave residuals on the slope that do not fall or slide into the cut area. *Slopes with low factors of safety for stability (less than 1.5) or low undrained shear strengths (less than 20 psf or 1 kPa) can pose higher restrictions on dredging designs and offsets for structures, resulting in additional undredged sediment as well as potential losses during removal.*

6.4.1.9 Groundwater/Surface Water Interaction

Groundwater infiltration into the surface water has little impact on hydraulic or mechanical dredging operations and is not a critical factor for selection. *High groundwater discharge rates, however, hamper efforts to keep an area dewatered to facilitate excavation.* Groundwater discharge rates can be particularly important if deeper excavations are needed to remove the contaminated sediment.

6.4.1.10 Sediment and Pore-water Geochemistry

Sediment and pore-water geochemistry parameters such as TOC, DOC, and POC can affect releases during dredging due to resuspension, as well as influence the management requirements for water generated during dewatering operations. In general, however, these parameters are not critical in the selection of removal as a technology.

6.4.2 Sediment Characteristics

6.4.2.1 Geotechnical Properties

One or more sediment properties such as particle (grain) size distribution, bulk density, porosity, water content, Atterberg limits (liquid and plastic limits and plasticity index), organic content, shear strength, and compressibility may influence the feasibility of dredging, dredging production rates, and contaminant losses during removal operations. *Sediments with higher liquidity indices (indices greater than about 3 or 4) promote more resuspension, release, and generated residuals (fluid muds) and are more difficult to capture with hydraulic dredges*, *auger dredges, or mechanical dredging equipment. Plain suction dredges may be better suited for removal of highly liquid sediments.*

Highly cohesive material may adhere to hydraulic auger dredges and mechanical dredging equipment, requiring frequent maintenance and slowing production. *For excavation, low bearing capacity may pose concerns for supporting removal and transport equipment and for* *infrastructure (such as roads or support mats); low undrained shear strength may limit the support available for an enclosure and for preserving stable shoreline slopes.*

6.4.2.2 Grain Size Distribution

Grain size distribution is not a critical factor in selecting removal as a remedial technology. The grain size distribution of the sediment, however, can be a factor in the selection and design of sediment processing (dewatering) and disposal methods.

6.4.2.3 Potential for Resuspension, Release, and Residuals during Implementation

Environmental dredging operations can result in some unavoidable contaminant releases. Sediments with a high potential for resuspension, release, and residuals (sediments with undrained shear strengths less than 0.5 kPa or 10 psf or a liquidity index greater than 4) pose concerns in selecting dredging as the remediation technology, particularly for mechanical dredging operations and horizontal auger dredges. Use of cutterhead dredges with articulated dredge heads and low rotational speeds can limit the resuspension, release, and residuals. These sediments can also be difficult to cap; therefore, resuspension, release, and residuals associated with removal need to be weighed against capping implementation challenges when selecting the remediation technology for sediments posing high risks. Deep water and high velocities or unfavorable wave conditions also increase the potential for losses. Consequently, the selection of the appropriate equipment is critical. *Excavation is generally best for sediments with high potential for resuspension losses or for containing source materials such as NAPL, because losses can be readily controlled.*

The presence of NAPL can lead to increased water and air releases during dredging, which may need to be mitigated. Studies have shown releases of 1-4% of the mass of contaminants dredged to the water column (frequently in the dissolved phase) even when resuspension controls are used. Increases in fish tissue concentrations of bioaccumulative COCs (such as PCBs) during dredging and for several years afterward have also been observed at environmental dredging projects.

Losses can be controlled, but not eliminated, by the proper selection of dredging equipment for the geotechnical properties and site conditions. *Hydraulic dredges tend to control losses better for soft sediments.* Plain suction dredges limit losses particularly for sediments with very low undrained shear strengths (less than 0.3 kPa or 6 psf) or a liquidity index greater than 4. Cutterhead dredges limit losses for sediments having greater strength and lower liquidity. Articulated cutterhead dredges produce lower losses and residuals, and auger dredges perform well for debris-free sediments with low liquidity and moderate shear strength. *Mechanical dredges tend to control losses better for stiff and sandy sediments.*

Closed buckets for environmental dredging have features to reduce resuspension, but generally do not perform as well as properly selected hydraulic dredges when removing sediments with low undrained shear strengths (less than 1 kPa or 20 psf) or a higher liquidity index (greater than 2.5). Environmental buckets can perform as well as hydraulic dredges for sediments with moderate undrained shear strengths (between 1 and 2 kPa or 20 to 40 psf), particularly in shallow water.

Open buckets can perform very well for sediments with higher undrained shear strengths (greater than 2 kPa or 40 psf) or lower liquidity indices (less than 2).

Depending on equipment selection, site-specific geotechnical properties, presence of debris, and hard bottom characteristics, environmental dredging operations can leave behind disturbed residuals.

Generated residuals are estimated to be 1-12% of the mass of contaminants present in the last production pass based on past field measurements. Plain suction dredges, particularly for the cleanup pass, may help to limit residuals. The effects of residuals can be mitigated by placement of residual covers or caps.

6.4.2.4 Pore-water Expression

Pore-water expression is not a critical factor in selecting removal as a remedial technology; however, it may be an important consideration in the selection and design of sediment processing (such as dewatering) and water treatment prior to discharge.

6.4.2.5 Benthic Community Structure and Bioturbation Potential

In general, benthic community structure and bioturbation potential are not critical factors in selecting removal as a remedial technology. These factors can be relevant, however, if rare or sensitive communities are present. *Removal of contaminated sediment will remove the benthic community along with its habitat. If rare or sensitive benthic communities must be protected, then removal may not be appropriate.*

If removed, benthic recolonization of the dredged surface (and any cover material placed over residuals) may require several years to fully recover all stages of the benthic community. Stage 1 recolonization tends to occur within a few months.

6.4.3 Contaminant Characteristics

6.4.3.1 Horizontal and Vertical Distribution of Contamination

The horizontal and vertical distribution of contaminants influences the applicability of a removal remedy. The site must be characterized sufficiently to specify the areal and vertical extent of the COCs. Characterizing the horizontal and vertical distribution of COCs can aid in determining whether the zone is acting as an ongoing source of COCs to the environment. This parameter is significant for removal because a larger horizontal or vertical extent of contamination results in a longer implementation schedule and higher cost. *Relatively higher concentration zones that are well defined (horizontally and vertically) and limited in extent (such as hotspots) are favorable for removal, while zones with a high degree of uncertainty in extent or with COCs that are dispersed are not suited for removal. In addition, areas with lower contaminant levels on the surface (in the bioactive zone) and with higher concentrations at depth can result in residual contamination in surface sediment that is higher in concentration than existed prior to removal.*

Understanding the depth of contamination is critical to designing the removal limits and avoiding undisturbed residuals. At some sites, placement of residual covers have been installed immediately following removal. In areas of high variability in COC extent (horizontal or vertical), definition of the removal area can be inadequate because straight-line interpolation of results may not represent the true variability of the contamination. Postdredging sampling may show that additional excavation is needed because of this variability. Excavation requires a well-defined areal and vertical extent of contamination to avoid expensive and time consuming changes during field operations. Additionally, infrastructure must be designed prior to removal (cofferdams, dewatering systems) and changes to that design may not be practical once the area is dewatered. Excavation also induces infiltration gradients and may mobilize contaminants such as NAPL upward into the excavation area.

6.4.3.2 Contaminant Type

The mobility and potential risks posed by the contaminant depend not only on the concentration but also on the nature of the contaminants. For example, some metals and low hydrophobicity organics may be far more mobile than hydrophobic organics. The higher mobility can result in increased releases during removal activities. Assessment of the type of contaminant and its relative mobility is moderately important when selecting removal as a technology.

Contaminant type also determines the hazards that might be present at the site. For instance, dry excavation poses the greatest concern for loss of volatiles and air inhalation hazards for workers and the community. *The presence of unexploded ordnance or munitions and explosives of concern (UXO or MEC, respectively) may also limit the application of removal technologies due to concerns regarding an unintentional detonation. Standard precautionary measures when UXO or MEC items are discovered are "recognize, retreat, and report."*

Contaminant type can also affect available disposal options. The previously mentioned explosives and other types of contamination may require disposal in a specially permitted facility (such as a RCRA- or TSCA-compliant facility). In some cases, contaminants or contaminated media may require treatment prior to disposal.

6.4.3.3 Contaminant Concentrations (Risk Reduction Required)

The level of contamination is not a critical factor in selecting removal as a remedial technology. Well-defined areas with disproportionately higher concentrations and more mobile contaminants (hot spots), however, are good candidates for removal because erosion and re-deposition of high contaminant concentrations may contaminate surrounding areas *The identification of removal areas is a site-specific determination and removal should justify the disruption to the ecosystem and community, short-term risks, use of landfill capacity, transfer of risk to the upland environment, implementation time, and costs for the effectiveness and permanence gained.* Note that greater resuspension, release, and quantity of residuals are associated with removal of higher concentration areas and risk reduction may be limited, but can be improved with resuspension controls and residuals management.

6.4.3.4 Exposure Pathways

Removal is compatible with all water exposure pathways, including those influenced by high contaminant mobility, high groundwater advection, NAPL presence, and deep bioturbation as well as hot spots. Areas with lower contaminant levels on the surface (in the BAZ) and higher concentrations at depth can result in residuals with contamination higher in surface sediment than existed prior to removal (increasing surface exposure concentrations). This issue has been addressed at some sites through placement of a residual cover immediately following removal. In addition, removal can create an airborne pathway by volatilization and fugitive dust, as well as other potential upland pathways at the processing and disposal site.

6.4.3.5 Presence of Source Material

Presence of mobile source material such as NAPL in the sediment is moderately important in the selection of removal as a remedial technology. Each of the removal technologies accommodates NAPL removal in different ways. Hydraulic and mechanical dredging can remove NAPL material to the extent that it is retained by the dredge equipment; however, both can result in release of NAPL to the water column. Resuspension controls can be moderately, but not completely, effective in containing NAPL releases, and methods that work better in containing releases also can create secondary issues. For example, in sheet-piled areas there can be increased residuals and increased air emissions. Excavation can provide better containment and control in the removal of NAPL material, but NAPL present beneath the excavation area may be subject to upward migration during dewatering and can lead to increased air releases.

6.4.3.6 Contaminant Mobility

Contaminant mobility is an important factor in the assessment of potential for resuspension, release, and residuals. Typically, the more mobile contaminants (such as VOCs and BTEX) are not present in sediments. The presence of these contaminants may indicate an ongoing source. More mobile contaminants exhibit higher potential for releases to the water column and air during removal.

6.4.3.7 Contaminant Bioavailability

Contaminant bioavailability is not a critical factor in selecting removal as a remedial technology. Removal in areas with lower contaminant levels on the surface (in the BAZ) and higher concentrations at depth can result in residuals with contamination levels that are higher in surface sediment than existed prior to removal (increasing bioavailable exposure concentrations). This phenomenon has been observed at dredging sites and has been addressed at some sites by the placement of a cover over residuals immediately following removal.

6.4.3.8 Contaminant Bioaccumulation and Biomagnification Potential

Contaminant bioaccumulation and biomagnification potential are not critical factors in selecting removal as a remedial technology.

6.4.3.9 Contaminant Transformation and Degradation

Contaminant transformation and degradation are not critical factors in selecting removal as a remedial technology.

6.4.3.10 Source Identification and Control

Watershed and ongoing sources must be identified during site characterization and effectively controlled. Ongoing sources can recontaminate treated areas, resulting in significant cost and resource losses. The effects of watershed sources, which are often beyond the control of those implementing the sediment remedy, must be accounted for and considered in defining the extent of sediment cleanup. If removal is the selected remedial technology, then the effects of ongoing sources can also help determine the level of post-removal residuals acceptable in the context of non-site-related releases or nonpoint source releases that will contribute to the future contamination of the site or surrounding sediment.

Significant sources must be identified and controlled in order to justify using removal technologies. When watershed and ongoing sources provide a source of contamination greater than the on-site source, dredging does not significantly reduce risks.

6.4.3.11 Ebullition

Ebullition is not a critical factor in selecting removal as a remedial technology. Sediments with higher ebullition potential, however, may result in odors that require management during transport, processing, and disposal.

6.4.3.12 Background Contamination

Just as ongoing sources limit the ability of a remedy to achieve objectives, the background levels of a contaminant may also limit the potential for remedy success. *It is generally not feasible to sustain remediated sediment sites at concentrations below background levels even if complete removal is achievable.* Background inputs should not be allowed to lead to recontamination that would exceed remediation goals.

6.4.4 Land and Waterway Use Characteristics

6.4.4.1 Watershed Sources and Impacts

As with any sediment-focused remedy, the effectiveness of removal can be offset by continued deposition of contaminated sediments to the sediment surface. Deposition of new contaminants can rapidly return the surficial layers to the pre-remedy conditions. The effects of such watershed sources (Section 2.2), which are often beyond the control of those implementing the sediment remedy, must be accounted for and considered in defining the extent of sediment cleanup. Control of watershed sources may require effort by multiple regulatory agencies and stakeholders. Complete control of ongoing watershed sources may not be possible, thus the long-term implications of any continuing source must be assessed.

6.4.4.2 Cultural and Archeological Resources

The presence of cultural and archeological resources should be assessed when considering removal. *Because removal operations disturb the ground, these operation may adversely impact cultural and archeological resources.* The proper authorities should be consulted to determine the appropriate measures needed during removal operations, which may include a range of actions from removal of the resources along with the contaminated sediment, to recovery of artifacts, to avoidance of the area to protect the resource. A site-specific plan may be developed to address cultural resources. The use of excavation may facilitate more effective identification, documentation, removal, and preservation of cultural and archeological resources.

6.4.4.3 Site Access (Staging, Treatment, Transport, and Disposal)

Site access determines the types of removal equipment that can be deployed and how removed sediment can be handled. In general, some access is needed to bring in labor and equipment for removal operations, possible staging and processing areas, water treatment operations, load-out facilities and disposal areas. *Sites with ready access to the water body and ample upland space available in the vicinity of removal are more amenable to removal than sites with limited access to the water and limited upland space.*

Site-specific access requirements vary depending on the removal method selected and disposal options available. A removal area or zone that is easily accessible in open water and from shore is favorable for removal. Hydraulic dredging operations typically require a larger staging area if off-site disposal is needed. A dewatering operation may be needed to process large volumes of sediment slurry, using equipment such as filter presses or Geobags coupled with water treatment, before transport to the disposal site. If a local CDF is available for disposal, then the staging area for hydraulic dredging may be reduced. Mechanical dredging generally requires a smaller staging area than hydraulic dredging because less carrier water is generated, but some space is needed for the transport of dredged sediment from the removal area to the processing and disposal location. For excavation, the removal area or zone should be easily accessible from shore, and the processing/staging area may be comparable to mechanical dredging. A safe, efficient means of transporting excavated sediment for disposal should be available, together with a suitable upland staging area.

6.4.4.4 Current and Anticipated Waterway Use

Current and anticipated waterway uses are important considerations in selecting removal as a remedial technology. CERCLA requires that site remediation achieve a level of cleanup (and residual contamination) consistent with the reasonably anticipated future use of the site. Removal can be combined with other objectives for purposes unrelated to cleanup (such as navigation or construction). Removal viability and extent should account for current and future needs for navigation and infrastructure, including utilities. Removal of sediments can increase water depth, thereby improving navigability in the removal area; however, removal in an active navigation channel can temporarily obstruct navigation and recreational uses during removal operations (see Section 6.3.5).

For hydraulic dredging, submerged and floating pipelines as well as the dredge itself must be coordinated with marine traffic because these facilities may obstruct navigation. For mechanical dredging, barge locations (both material transport and the dredge barge) must be coordinated with marine traffic and with lock and bridge operations. For dry excavation, the isolation structure may also obstruct navigation.

6.4.4.5 Current and Anticipated Land Use

Current and anticipated land use can be important factors in selecting removal as a remedial technology. An access area that is readily available, of adequate size, and compatible with current and future land use is favorable for removal (see Section 6.4.4.3). Upland areas, which may be incompatible with access requirements for removal, make removal less feasible. When evaluating compatibility for staging areas, overhead clearance should be considered. Current and future land use may influence removal design, type of removal equipment that can be deployed, and sediment handling.

6.4.4.6 Presence of Endangered Species and Habitat

Removal of sediment also removes any organisms present in the sediment as well as the habitat it may provide. Any unique or sensitive species and habitats present in the sediment targeted for removal may be removed or disrupted. The extent of impact and disruption must be assessed on a site-specific basis, but is generally directly related to the extent of removal and overall sensitivity of the species and habitats. Engineering controls can be evaluated to help protect surrounding areas, but the removal area is inevitably affected. Removal operations can often be restricted to periods in which endangered species are less prominent or when spawning activities are not occurring. In some completed projects, habitat restoration has been incorporated into the design (such as backfilling to appropriately designed elevation, plantings, and placement of a cover); however, time is needed for habitat recovery, and some habitats may be very difficult to restore. *In cases where the risk of habitat loss is great, removal may be avoided or limited in order to protect the resources.*

Increased water depths created by removal operations can also affect habitat quality. *Removal can be favorable in areas where an increase in water depth does not degrade habitat. Conversely, removal is unfavorable in areas and zones where an increase in water depth degrades habitat (for instance, where removal converts historically shallow water habitat to unwanted deep water habitat).*

6.5 Evaluation Process

The selection of sediment removal as a remedial approach should be based on an overall assessment using criteria appropriate for the specific site being investigated. Sometimes, a single site may use hydraulic dredging in some segments and mechanical dredging in another segment, in order to leverage the advantages of each. While CERCLA criteria (or similar) are commonly used to evaluate these approaches, each state may have its own set of evaluation criteria. Generally speaking the criteria fall into the three primary categories: risk, practical considerations, and cost.

Typically, the primary goal of the evaluation process is to select an approach that is permanently protective of human health and the environment, can be readily implemented, and is cost-effective. Often, alternatives developed for a site consist of multiple or combinations of approaches, such as varying degrees of removal, capping, in situ treatment, or MNR in different areas of the site. The evaluation process (Chapter 2) offers a consistent approach for selecting and applying these remedial technologies.

Sediment removal typically requires a higher initial monetary investment than capping or MNR. Therefore, to be cost effective, removal should provide a higher degree of effectiveness, permanence, or implementability than other approaches. When assessing protection of human health and the environment, the overall net risk reduction must be considered, including risks associated with implementing the remedy along with risks remaining after the remedy, as compared to baseline risks. The risks of implementing the remedy typically include resuspension and release of contaminants during removal, air emissions, worker-related risks, traffic risks, and others. Residual risks include risks from contamination that remains after removal activities are completed, such as residuals (both generated and undisturbed), areas not dredged, and inputs from continuing sources. Even when dredged materials are hauled to an off-site disposal facility, relatively large on-site infrastructure may be required for sediment dewatering and pretreatment operations.

Conditions at a site that may support sediment removal as a potentially viable remedy or a remedy component that is favorable for selection over capping, in situ treatment, or MNR include the following:

- zones currently acting as an unacceptable source of contamination to the water column and/or overlying biota (or could reasonably become an unacceptable source in the future)
- zones not reasonably amenable to capping, in situ treatment or MNR, such as navigational channels, high energy, or erosional environments
- isolated zones such as hot spots or high concentration areas, which present a much higher risk among larger areas of lower risk
- zones of contamination with a more mobile contaminant source, such as NAPL, which cannot be adequately contained using other remedial options
- zones with stable slopes along an accessible shoreline that can readily be isolated and dewatered for easier removal
- areas where water depth and other site conditions (such as wind and currents) are suitable for effective control of removal-related resuspension or releases
- sites located where relatively economical options for handling and disposal of the dredged material are available, such as a CAD facility, a CDF, or a local landfill
- removal activities that are acceptable to neighboring businesses and residences

Conditions at a site that are generally not favorable for selection of sediment removal over other technologies include the following:

- large zones with relatively low-concentration contamination, where a low net risk reduction would be expected from a removal remedy
- zones in low-energy (low erosive force) environments, which have low likelihood of resuspending or eroding surface sediments
- zones where higher contamination is buried beneath cleaner sediment, and where a relatively low likelihood exists for the buried contamination to be mobilized under a reasonable future event (such as a 100-year flood) at concentrations that would pose unacceptable risk
- zones with significant debris or shallow sediments resting on rock, which would exacerbate resuspension and residuals resulting in a lower net risk reduction
- zones in sensitive aquatic environments, where removal-related resuspension or releases would be undesirable
- zones that might receive contaminants from continuing sources after sediment removal
- zones that are difficult to access (for example, under bridges or piers with closely spaced pilings)
- deep water depths that may reduce the effectiveness of dredging and resuspension control equipment (such as silt curtains)
- zones that have utilities beneath the contaminated sediment, where damage to the utility may occur

A situation where dredged areas must be remediated again due to continuing sources of contamination should be avoided. Discussions with all parties, including community and tribal stakeholders and watershed management agencies may help resolve recontamination issues prior to large financial commitments. These discussions may lead to a more proactive regional management plan if a sustainable and productive resource can be recovered for use.

This list, while not comprehensive, provides general guidance on zones that may be amenable to removal when compared to capping, in situ treatment, or MNR/EMNR. A risk-based management decision should balance the predicted net reduction in risk, permanence, and implementability against overall costs (both implementation and long-term operation and maintenance costs), and the selection of a remedial technique should only occur following comparative evaluation of all potentially viable remedial techniques.

6.5.1 Protection of Human Health and the Environment

Dredging operations attempt to achieve protection of human health and the environment through removal of COCs from the aquatic environment. When assessing the degree of overall protectiveness, important considerations include:

- residuals that remain in the bioactive zone after dredging (incorporating any residual management like backfilling or capping dredged areas)
- releases which may cause contamination in nondredged areas

- other short-term impacts (described in this chapter)
- the loss of habitat in removal areas (incorporating time for restoration of such habitats)
- the degree of long-term protectiveness of the final disposition of removed sediments (such as CDF, landfill, or beneficial use)

6.5.2 Compliance with ARARs and State or Tribal Acceptance

Compliance with the chemical-specific ARARs is achieved to the degree that removal of sediment from the aquatic environment results in reductions of contaminant concentrations to specific ARAR concentrations. The act of dredging triggers a number of action-specific ARARs, such as Rivers and Harbors Act, Clean Water Act dredge and fill requirements (USACE, state water quality certifications), and depending on the methods used for processing and disposal, many others (NPDES, TSCA, RCRA, DOT, and others). Location-specific ARARs can include wetlands permitting, floodplain permitting, coastal zone management, and National Parks requirements. State historic preservation requirements and requirements under the Threatened and Endangered Species Act also must be considered. Waivers of some ARARs can be considered at some sites.

6.5.3 Long-term Effectiveness

Dredging remedies attempt to achieve long-term effectiveness and permanence by removing contaminated sediment from the aquatic environment to achieve risk-based goals. These remedies manage the removed sediment in a manner that treats or contains the contamination for the long term. In cases where dredging has been unable to achieve the goals (residual contaminant concentrations are in excess of the goals), dredged areas at some sites have required subsequent placement of clean backfill or an engineered cap.

6.5.4 Short-term Effectiveness

Dredging operations resuspend sediments, resulting in the release of contaminants. Operational controls and physical containment systems (silt curtains, sheet piling, and air curtains) can be used to reduce the release of contamination from the dredge area, but these controls do not completely eliminate the release. Tools and models are available to estimate those releases and their effects on the environment, and have been used at a number of sites (Hudson River, Fox River). In addition to resuspension, other potential short-term impacts must be considered, including air emissions (from water column releases, sediment transport releases, and dewatering or processing operations). Nuisance aspects such as noise, lighting, and odors should also be considered. Finally, the personnel safety risks associated with the construction, dredging operations, and transportation of sediments should also be considered.

6.5.5 Reduction in Toxicity, Mobility, and Volume through Treatment

Dredging removes sediment from the aquatic environment and therefore reduces the toxicity, mobility, and volume of contaminants contained in the removed sediment. Residuals and resuspension reduce some of the benefits of removal. Therefore, dredging should be undertaken when removal results in a net benefit and when site conditions are suitable for this approach.

6.5.6 Implementability

Dredging and disposal services are commercially available for implementation of sediment removal. If the project is large or if specialized equipment is needed at a specific site, however, the availability of qualified contractors, facilities, and equipment must be closely assessed. Areas which present difficult or remote access, infrastructure, marginally stable slopes, shallow water, and sensitive habitats should be reviewed to determine the practicability of removing the sediments. Designers should assess whether the damage incurred to develop access and remove the habitat is warranted. In addition to the removal activities, the availability and proximity of property and facilities for sediment offloading, processing/treatment, and disposal should be reviewed. Permitting requirements for dredging projects can include assessments of rare, threatened and endangered species, cultural or historical resources, and other environmental factors.

6.5.7 Cost

Dredging is typically the most expensive remedial approach when compared to less intrusive approaches such as MNR, in situ treatment, and capping. In addition, the uncertainties of the potential costs tend to be higher due to the potential for sediment volume and removal depth to increase once removal operations begin, and uncertainties related to post-removal residuals contingency actions such as backfilling or capping. Typically, a large component of total removal cost is the cost for processing, transport, and disposal of the dredged material. A detailed site-specific cost estimate is vital early in the project (during the FS stage), and should consider all the components of the costs, including dredged sediment handling, long-term monitoring, and maintenance. An uncertainty analysis can be useful when weighing the costs of removal against other options, because many removal projects have experienced higher actual costs than expected. Project managers should consider cost data from other completed projects by incorporating project specific factors and conditions when developing site-specific cost estimates.

6.5.8 Community and Tribal Stakeholder Acceptance

At many sites, removal is initially the preferred alternative among stakeholders because it has the potential to permanently remove contaminants from the sediment. Stakeholders should be engaged early in the assessment process and be provided with a full objective assessment of the benefits and costs of a removal approach. See Chapter 8 for additional information on tribal and stakeholder concerns.

6.5.9 Green and Sustainable Remediation

Typically, removal requires more intrusive work and more construction equipment than other approaches with resulting consumption of more resources (fuel, energy, labor). The use of low sulfur fuels and biodegradable hydraulic fluids can reduce the potential environmental impacts, but these impacts cannot be eliminated. One important GSR consideration is beneficial use of the dredged material, which can reduce transportation (if re-use is closer to the site than the disposal facility), reduce processing needs (if less dewatering or processing is required for placement), develop usable land (for example, for a CDF), and minimize the use of commercial landfill capacity. ITRC (2011b) offers additional GSR guidance in *Green and Sustainable Remediation: A Practical Framework*.

6.5.10 Habitat or Resource Restoration

Dredging removes existing habitat in the areas where removal is required and may also disrupt habitats in order to develop access and processing/handling facilities. Best efforts can be used to replace the habitat destroyed by the removal operations (if replacement is possible), but habitats need time to recover (in some cases, decades). Also, the removal of existing, mature habitats can make areas more vulnerable to invasive species infestation. These adverse effects should be examined along with the benefits to assess whether removal may result in more damage than benefit.

6.6 Monitoring

Developing an appropriate scope for monitoring a sediment removal remedy is best done on a site-specific basis. This section outlines the monitoring elements to consider when developing the scope of a monitoring program for a contaminated sediment removal project (see Table 6-1). Construction monitoring is typically conducted during remedy implementation. Operational monitoring is performed during sediment removal and post-remedy implementation. Performance and long-term monitoring aid in determining remedy effectiveness.

6.6.1 Construction Monitoring

Water monitoring is typically used to provide data regarding resuspension and release of contaminants during removal operations.

- *Locations*. Monitoring locations can include near-field and far-field monitoring. Near-field monitoring includes the immediate vicinity of removal operations and far-field includes locations further downgradient of operations at key monitoring points (beyond mixing zone, upstream of water intake, or upstream of confluence with receiving waters). The objectives for monitoring each location may be different and help to define the appropriate monitoring location.

  Near-field locations may be used to provide ongoing feedback on the dredging operations. For example, turbidity is often monitored near the dredging operation to assess the effectiveness of silt curtains. Far-field locations may have a different purpose, such as monitoring contaminant levels to assess impacts of the removal operation on water quality (comparison with water quality criteria) or to protect a water supply intake.

- *Parameters*: Parameters to be monitored can include field measurements (such as turbidity, dissolved oxygen, pH, and temperature), physical parameters (such as total suspended solids and TOC), and chemical parameters (such as COCs and ammonia). The parameters can be different for the various locations.

6.6.2 Post-Remediation Monitoring

Post-remediation monitoring evaluates the effectiveness of contaminated sediment removal in reducing or eliminating exposure and risk. At many sites the reduced or eliminated risk eventually results in a decreasing trend in tissue concentration of exposed organisms.

6.6.3 Performance Monitoring

Physical and chemical monitoring is typically used to verify that removal has been adequately completed.

- *Physical Monitoring*. A physical survey, bathymetric survey, or both are often used during sediment removal operations to verify that removal has been completed in the target areas and that depths specified in the design have been reached. When the design objective is to both dredge and backfill a targeted volume of sediment, bathymetric surveys become the primary indicator that the removal operation is complete. Physical inventory of the volume or mass of sediment dredged can confirm completion of the target dredging. When sediment removal is designed to be followed by backfilling dredged areas with clean material, there is greater reliance on physical measurements. These measurements include bathymetry (depth) and dredged sediment inventory (volume), to establish performance.
- *Chemical Monitoring*. When the design objective is to dredge only (no backfilling), chemical monitoring verifies that concentration-based chemical goals have been achieved, that the exposed sediment does not pose an unacceptable risk, and that the dredging is complete. Sampling and analysis of sediment residuals remaining after removal operations is generally required for the chemicals of concern. The residual concentrations can be compared to cleanup goals established for the site to determine whether dredging is complete and to determine whether some additional measures are necessary (such as re-dredging or backfilling). When dredging is designed to be followed by backfilling with clean fill, chemical monitoring of the dredged area becomes less important.

6.6.4 Long-term Effectiveness Monitoring

ASTSWMO's Sediment Focus Group has prepared a framework for long-term monitoring (ASTSWMO 2009) which describes monitoring of a sediment site, particularly long-term monitoring following a remedy. ASTSWMO recommends that decision rules for long-term monitoring should include site-specific criteria to continue, stop, or modify the long-term monitoring, or recommend taking an additional response action. The main elements of such a decision framework are likely to be the parameters of interest; the expected outcome; an action level; the basis on which a monitoring decision will be made; and monitoring decision choices (USEPA 2004). ASTSWMO recommends that the long-term monitoring strategy and decision framework be established early in the process of remedy selection, preferably in the FS discussion of various alternative remedies. The time required to attain long-term monitoring objectives under various alternatives should be clear to participants and stakeholders.

Long-term monitoring is required to determine whether the removal actions continue to effectively mitigate exposure and continue to meet site specific RAOs. The emphasis of long-term monitoring depends on whether RAOs are framed in terms of sediment concentrations or biota tissue concentrations. If the latter, then long-term monitoring typically includes testing the benthic infaunal community or collecting fish tissue samples to determine whether levels meet or are on a trend to meet RAOs. Depending on the exposure endpoint, other species (such as piscivorous birds or mammals) may be tested to evaluate the possibility of ongoing exposure. When residuals remain, chemical monitoring of pore waterfrom near surface sediments may be conducted to evaluate the potential for contaminant flux entering the water column at unacceptable levels. Bathymetry surveys can confirm that backfill remains in place.

Table 6-1. Measures potentially applicable to meet monitoring objectives for removal

Objectives	Measures		
	Chemical	Physical	Biological
Operations Phase			
Determine whether the established performance metrics for remedy implementation and construction are being met.	• Dissolved oxygen, pH, temperature, ammonia, sediment COC concentrations • Air monitoring at locations upwind and downwind of operations to assess potential impacts from removal operations • Discharge monitoring if water generated during removal, which requires discharge back to a waterway	• Bathymetry survey • Turbidity • Total suspended solids • Total organic carbon	NA
Post-remediation Phase			
Performance: Determine whether the remedy has been successful in reducing concentrations of COCs in sediment to acceptable levels (RAOs) defined in the remediation decision documents, and whether specific criteria (such as cap thickness or dredge depth) have been achieved.	• General chemistry • COCs concentrations (pore water/ near surface sediments)	Bathymetry survey	NA

Table 6-1. Measures potentially applicable to meet monitoring objectives for removal (continued)

Objectives	Measures		
	Chemical	Physical	Biological
Effectiveness: Determine whether concentrations in affected media continue to meet RAOs (or continue on a decreasing trend expected to meet RAOs) and involve monitoring fish to determine whether tissue levels meet (or are expected to meet within some established time frame) the RAOs that are protective of human health as well as piscivorous birds and mammals.	• General chemistry • COC concentrations (pore water/ near surface sediments, fish or other biota)	Bathymetry survey	Benthic infaunal survey

6.6.5 Air Monitoring

Air monitoring is sometimes conducted if air emissions during removal are expected to be of concern.

- *Locations*. Typically locations are selected upwind and downwind of operations of concern (for example, removal, transport of sediment, or processing of sediment) to assess potential net impacts from removal operations. Local meteorological data, such as wind speed and direction, are also used to in selecting appropriate monitoring locations.
- *Parameters*. The parameters to be monitored are determined based on the air emission concerns identified during remedy selection and remedy design. In addition, the type of sampler selected is based on the parameters to be measured and the required sensitivity of the measurements.

6.6.6 Discharge Monitoring

If water generated during sediment removal and processing must be discharged back to a waterway (or to a POTW), then monitoring of the water discharge must be considered. Typically, the specifics of this monitoring (location, frequency, and parameters) are determined on a site-specific basis in consultation with the agencies providing regulatory oversight.

6.7 Case Studies for Removal by Dredging and Excavation

Numerous sediment removal case studies, at different stages of completion, were reviewed for this document and are summarized in Tables 6-2 and Table 6-3. A summary of dredged material handling at sediment remediation sites is provided in Table 6-4. In many of these case studies, mechanical dredging was either used alone or in conjunction with other removal methods. A combination of mechanical and hydraulic dredging or hydraulic dredging alone was used at other sites.

Table 6-2, Mechanical dredging case studies

Table 6-3, Hydraulic dredging case studies

Table 6-4, Dredged material handling at sediment remediation sites

6.7.1 Mechanical Dredging Site Experience

At some sites, mechanical dredging was conducted dry, in a sheet pile enclosure that had been dewatered, sometimes aided by a bypass pump to divert water away from the enclosure. At other sites, both dredging and excavation were conducted on different segments of the same site. Compared to the studied hydraulic dredging sites, most of which were relatively shallow (water depth less than 20 ft), at least five of the mechanically dredged sites reported water depths of greater than 20 ft, indicating that water depth may be a factor in technology selection.

At most sites where detailed volume-of-dredged-sediment information was available, more sediment was actually dredged than planned. The reasons varied, resulting from later discovery of additional areas of contamination, multiple dredging passes, or events when confirmatory samples indicated that project cleanup goals had not been achieved. Several sites studied reported success in meeting postdredging cleanup goals without backfilling. Two of these successfully dredged sites were in relatively deeper water (water depth greater than 20 ft). At two of the successful sites, one in shallow and one in deeper water, cleanup goals were framed as surface weighted average concentrations (SWACs). Nearly half of the sites studied used backfill with clean material after dredging to help meet cleanup goals. At the Fox River and Green Bay OU 2 to OU 5 backfilled sites, the cleanup goal had been framed as a SWAC. Area average cleanup concentrations were also used for surface and deeper sedimentduring dry excavation at the Housatonic River site.

Experience shows that mechanical dredging can be effective for areas that contain large debris, where dredging will occur in small or confined areas, or where dredged sediment must be transported by a barge to a disposal or treatment facility. Production rates for mechanical dredges are typically lower than those for hydraulic dredges when sized for a given project. Mechanical dredges were often selected for dredging projects in confined areas such as areas near docks and piers. Mechanical dredges provided one of the few effective methods for removing large debris and are adaptable to land-based operations. As expected, mechanical dredging captured less water with the sediment, as compared to hydraulic dredging. While dependent on sediment composition, minimal dewatering was generally required for mechanically dredged material before treatment and transportation for disposal. As a result, mechanical dredging often required smaller staging areas for on-shore support operations, compared to hydraulic dredging, which limited effects on current land use.

For mechanical dredges, a conventional clamshell dredge (crane with a cable-suspended bucket) has been shown to work well in the field with sediment that is easy to penetrate. These dredges can remove thin or thick faces of sediments effectively. Backhoes can be used for removing contaminated sediments when more conventional buckets are less effective. Field experience also shows that backhoes can be used when debris is present that would prevent conventional clamshell buckets from closing. Backhoes are often considered when there are hard bottoms or the sediments are more consolidated and are harder to penetrate. When sediments have high shear stresses or contain stiff clays or highly cohesive sediments, they can reduce a clamshell's ability to penetrate the sediment. If the clamshell performance diminishes, then backhoes may be a better alternative. A clamshell bucket mounted on a backhoe arm has sometimes been used to dredge stiff sediment. Backhoes are normally land based, but may be operated from a barge; however, their use is predominantly in shallower depth channels rather than deep draft channels. Backhoe excavators also have better location control and accuracy over the penetration depth since they can use the mass of the equipment and the rigid arm to achieve the required depth in more consolidated sediments.

Mechanical dredges with clamshell buckets suspended by wires have some difficulty in digging slopes since they tend to "stair step" the slope whereas backhoes can more neatly dress the slope. Clamshell buckets can have difficulty on steep slopes where the bucket tends to fall over or slide down the slope. Since mechanical dredging is often slower than hydraulic dredging, the effects of shoaling, deposition, or erosion on the removal operation are more likely and warrant consideration. Typically removal does not begin until after the source of contamination has been eliminated. Therefore, any shoaling or deposition during operations is most often clean sediments and can readily be considered during design and planning.

Mechanical Dredging Site Experience

Mechanical dredging has a relatively slower production rate, but has been particularly useful at sites with stiffer sediment and/or sites that are spatially difficult to access (such as near piers or wharfs). Mechanical dredging has also been used in the field as a first step to clear debris and prepare for faster higher production hydraulic dredging.

At the sites studied, sediments that were more consolidated and required some cutting action to dislodge were particularly suitable for mechanical dredging. Additionally, mechanical dredging was better suited for higher precision dredging, such as when working around in-water infrastructure or when removing small deposits. Often, a safety setback was used around such structures to reduce the risk of undermining or damaging the structure. Additionally, sediments did not always behave as expected, so in order to reduce the risk of slope failure or bank instability, mechanical removal sometimes included buffers. Challenges encountered during mechanical dredging at these sites tended to include the need for management of residual contamination left behind after dredging and resuspension control during dredging.

At the Messer Street site, the flexibility of the dredge operator to change the dredge type and vary depth of in-river operation demonstrates that mechanical dredging is one of the most adaptable sediment removal methods in environmental dredging.

6.7.2 Hydraulic Dredging Site Experience

At the sites described in Table 6-3, the primary advantages of hydraulic dredging over mechanical dredging (and the reasons for its selection) were higher production rates, less resuspension of fluid sediment, and more efficient transportation of solids in a single step from the dredge site to the onshore processing area. A hydraulic dredge and slurry pipeline system eliminates the need for transfer of material from the dredge to barges, which reduces energy use, noise, and vessel traffic, and keeps the sediment contained. At suitable sites, these are substantial advantages. Where hydraulic dredging is at a disadvantage relative to mechanical dredging is in its limited ability to handle adverse site conditions, such as sediment with large debris or proximity to infrastructure (such as sediment under piers, between pilings, or closely overlying bedrock). The larger volume of water generated that typically requires treatment is another disadvantage of hydraulic dredging.

As with mechanical dredging, the physical characteristics of the sediment in its native environment are important factors in the selection of the hydraulic dredging, dewatering, and disposal equipment. The smaller hydraulic dredges used in environmental applications are capable of removing relatively soft to medium stiff sediment. Larger hydraulic dredges used in navigation applications are capable of removing very stiff sediment, but may have higher mobilization costs. Hydraulic dredges are not suited for dredging in areas with debris larger than the diameter of the pump impeller inlet or the hydraulic cutter clearance.

Hydraulic Dredging Site Experience

Hydraulic dredging offers the potential for a higher production rate at sites that are suitable (for example, sites without significant debris or stiff sediment). Sediment dredged with this method typically has a higher water content and may require larger staging areas, in part to support more extensive dewatering operations.

At suitable sites, such as the New Bedford Harbor site, a major advantage of hydraulic dredging was that the dredge pump could transport sediment to a reasonably distant discharge point on shore. To facilitate pumping over larger distances, however, considerable water was entrained with the sediment, compared to other sediment removal methods. Dewatering was a significant effort and cost driver at hydraulic dredging sites and a large volume of excess water often was treated before discharge or reuse.

Smaller hydraulic dredges appear to have worked well in relatively shallow waters that may have been inaccessible to larger hydraulic dredging equipment (or to barges with mechanical dredging equipment). Standard hydraulic dredges can operate in water depths of 30– 50 feet and special modifications or equipment (such as a ladder pump) may be included in dredging at greater depths (not common at the sites studied). Larger or specialty hydraulic dredges could be economical when large volumes of sediment need removal, whereas a relatively shallow cut over a large area can make a larger dredge inefficient.

Hydraulic dredging appears to have been used primarily at relatively shallow sites, with water depths reported at 20 ft or less for all of the sites studied. Many of the sites used hydraulic dredging in conjunction with capping or MNR. For the sites evaluated, capping and MNR were usually conducted for the less contaminated areas surrounding the dredged sediment.

Dewatering was a major operation at hydraulically dredged sites (Table 6-4) because the sediment was retrieved with higher water content (to keep the solids fluidized during pumping). Dredged material was often pumped large distances to be dewatered in isolated cells, coffer dams, filter Geotubes, hydraulic separation, filter presses, or on-site CDFs. Following dewatering, the dredged material was transported by road or rail to an appropriate landfill. Sometimes the sediment had to be stabilized on site with fly ash or cement before transport. At Formosa Plastics, hydraulic dredging was replaced with mechanical dredging because of severe on-shore limitations in conducting the required dewatering operation.

6.7.3 Site Experience with Excavation

At some sites, excavation may offer better control over the dredging-related risks of resuspension and release of contaminated sediment with the use of proper enclosures. Six of the sites summarized in Table 6-1 were excavated after draining the overlying water column in a sheet pile enclosure. At two more sites, both wet dredging and excavation were conducted on different segments of the site.

If appropriate for the site, excavation can be less costly than dredging if land-based transportation infrastructure can facilitate better access and more timely removal operations. Typically, draining the water column above near-shore sediment provides easier access to underlying sediment at the sites where excavation is conducted. In the case of the Brookhaven Lab, Peconic River site in Upton, NY, near-shore sediments were removed by terrestrial excavators and placed on barges, hauling trucks, or railcars. The sediments were transported to transfer points, landfills, treatment sites, or designated reuse sites. The Housatonic River case study also illustrates the use of excavation.

Table 6-2. Mechanical dredging case studies

Site	Contaminants/Targets	Site Description	Sediment Handling	Results
Brookhaven, Peconic River, NY, 2005	Hg, Ag, Cu, PCB SWAC for Hg Target Volume-1,134 tons; Tons Removed-1,134	Freshwater; 0-30 ft water depth excavation; silt curtain for resuspension; clean sediment backfill for dredged area and marsh res-toration	Drying pad dewatering; wet cells for decanting; contaminated sediments landfilled	Cleanup levels met LTM, MNR in place
Kokomo Creek, Wildcat Creek Continental Steel, IN, 2007, OU 3	PCB, PAH, Ar, Be SWAC Target volume removed: 16,000 yd^3 Total weight removed: 22,467.12 tons	Freshwater; 1-4 ft water depth; 2 miles, sed-iment thickness 0.4-2.17 ft; combined excav-ation, hydraulic dredging	Dewatered; drying pads, sand and activated char-coal filtering; landfilled; CAMU; PCB and VOC dis-posed off site at permitted facility	Cleanup levels met MNR in place
Eagle Harbor, Wycoff, WA, 1997	Creosote, PCP, PAH, Hg, Pb, Cu, Zn Target volume Hg 1,500-1,900 yd^3	Marine; 15-45 ft water depth; sheet piling; Sediment thickness 0.7 yd depth	Dewatered; hotspot CDF disposal; large material landfilled; clean sediment backfill; capping	Goals met; capping exceeded cleanup standards; LTM/MNR PAH intertidal area

Table 6-2. Mechanical dredging case studies (continued)

Site	Contaminants/Targets	Site Description	Sediment Handling	Results
Dupont, Gill Creek, 1992	VOC, Hg, PCBs Target volume: Area 1 3400 yd^3, Area 2 160 yd^3, Area 3 40 yd^3 Actual Volume 8,020 yd^3	Freshwater ; 250 ft section of Gill Creek near Niagara River; sites OU 3 – OU 5	Dewatered with sand bags and cofferdams; stabilized with fly ash and kiln dust then disposed of in TSCA/RCRA landfills 230 yd^3 incinerated	Concentrations lowered by dredging; no capping needed; planned 5 yr monitoring of sediments and water
Formosa Plastics, TX, 1992	Ethylene dichloride Target volume 330 yd^3 Actual volume 7,500 yd^3	Marine, 25-30 ft water depth; silt curtain	Cofferdam dewatering; partially dewatered sediments mixed with cement and barged to offload and disposed at a RCRA-compliant landfill	Goals met; hydraulic dredging did not work; used barged mechanical dredging instead
Town Branch Creek, KY, 2000	PCB Target Volume 290,000 yd^3 Actual Removed 239,000 yd^3	Freshwater; dams with bypass pumping	Contaminated sediments sent to TSCA facility, non-TSCA sediments sent to local SW landfill	Goals met temporarily due to a NAPL source; NAPL recovery system installed

Table 6-2. Mechanical dredging case studies (continued)

Site	Contaminants/Targets	Site Description	Sediment Handling	Results
Fox River, Green Bay WI OU 2-OU 5 OU 2,OU 3 – 2013 OU 4,OU 5 – 2017	PCBs, Dioxin, Furan, DDT, Ar, Pb, Hg Target volume – combined 3.5 million yd^3	Freshwater; 6-20 ft depth sites contain 12 dams and 17 locks; contaminated sediment depths: 2-40 inches; contaminated sediment area 33 miles long and 1,600 square miles	The type, extent of dredging and disposal information to be determined	Work in progress; mechanical dredging to be used on OU 2 20-mile stretch and MNR for 1,600 square miles of Green Bay; potential capping for damaged riverbanks and sand cover
Hooker, NY, 1998	VOC, Hg Target volume 19,600 yd^3 Actual Volume 28,500 yd^3	Freshwater, 0-2 ft; 2.5 acres in river embayment; berm construction to contain resuspension; on-site landfill	Cofferdam and sumps to control water infiltration; no capping for river but capped on land; sediments placed into on-site landfill, on-site landfill in river embayment	No capping needed in water, but was used on landfill

Table 6-2. Mechanical dredging case studies (continued)

Site	Contaminants/Targets	Site Description	Sediment Handling	Results
Housatonic River, MA, 2002	PCBs, NAPL Target Volume (hot-spot) 2,800 yd^3 Half mile 18,138 yd^3	Freshwater, 0-8 ft; contaminated sediment area 0.5 miles; sheet piling, dewatered for excavation; no silt curtains; dry excavation	Cofferdams, sumps; contaminated sediments placed in on-site facility	Periodic NAPL release slowed project. Isolation cap installed on area not dredged; dredged areas backfilled and seeded/replanted
Messer Street Manufactured Gas Plant, Laconia, NH, 2001	PAHs, VOCs, TPH	Freshwater, 5 ft water depth; 3 acres, dredge depth 2-5 ft, Dry and wet excavation, silt curtains, Sheet pile barrier, mechanical cable arm clamshell and hydraulic bucket used; backfilled with mostly gravel materials	Sheet pile barrier for dry excavation; dewatered; sediment disposal by thermal desorption facility and RCRA-compliant landfill	Clam bucket difficulty with sandy sediments; pre- and postdredging concentrations significantly different; successful cleanup

Table 6-2. Mechanical dredging case studies (continued)

Site	Contaminants/Targets	Site Description	Sediment Handling	Results
Money Point, VA, 2009-present	PAH, PCP, dioxins, Ar, Cr, Cu, Pb, Zn Target volume 80,800 yd^3	Marine; 1.7 acres wetlands/forested shoreline; sediment thickness up to 6 ft; earth-moving equipment and clamshell/bucket dredge used; silt curtains, absorbency booms, crane/barge used; dredged areas to be backfilled with clean sand and topsoil	To be shipped by barge to be land transported to landfill for thermal treatment. Some sediments to be disposed on site	Work in progress. Petroleum sheen from disturbed sediments; Mummichogs to be sampled 1-2 years for cancer until background levels are reached
Natural Gas Compressor Station, MS, 1997	PCBs Target volume 51,432 yd^3 stream sediment, 8,290 yd^3 floodplain soils Actual volume removed 23,883 yd^3	Creek bed/flood plains 2 miles, sediment depths 8-10 ft, 15-25 ft wide Excavation with creek flow pumping Backfill with seeding and mulch.	No dewatering; some sediments mixed with lime and fly ash to make them suitable for land transport	Goals met

Table 6-2. Mechanical dredging case studies (continued)

Site	Contaminants/Targets	Site Description	Sediment Handling	Results
NS McAllister Point Landfill, OU 4, Rhode Island, 1996	PCBs, PAHs, anthracene, fluorine, pyrene, metals, Cu, Ni, debris Target volume 34,000 yd^3 Actual volume removed 2,700 m^2	Marine, 3 ft MLW; landfill revetment; 47 acres adjacent to landfill; mechanical clamshell, silt curtains	Decontamination and recycling of dredged rocks; other dredged material sent off site for recycling or disposal; remaining dredge disposed of at landfill or other site	Goals met. Upland revetment regraded, capped, and re-vegetated
Ottawa River, Canada, 1998	PCBs Target volume 6,500 yd^3 Actual volume removed 6,800 yd^3 tributary sediment; 1,653 yd^3 wetlands soil	Water depth 0-40 ft; tributary and adjacent wetlands; tributary 975 ft x 9 ft wide; conventional earth moving equipment; steel sheeting installed at tributary mouth to hydraulically isolate tributary from river; water pumped, treated on site; backfilled with clean fill	Excavated material transported to dewatering pad, fed into pug mill; 14,975 tons of dewatered sediments disposed as TSCA waste; wetlands soils disposed as non-hazardous waste RFD and mixed with stabilizer or stabilizing agent and sent to landfill	PCB levels reduced

Table 6-2. Mechanical dredging case studies (continued)

Site	Contaminants/Targets	Site Description	Sediment Handling	Results
Queensbury NMPC OU 1, 1996	PCB Target volume 5,000 yd^3 Actual volume removed 6,800 yd^3	Hudson River shoreline; 0.3 acres; water level lowered to expose riverbank and shoreline using local dam; silt fence, Jersey barriers wrapped in geotextile installed on upper inland boundary; back-filled with topsoil and rip-rap; upland seeded and revegetated.	Dewatering pads used for one week; contaminated sediments transported to off-site landfill.	PCB levels reduced.

Table 6-2. Mechanical dredging case studies (continued)

Site	Contaminants/Targets	Site Description	Sediment Handling	Results
Reynolds, NY, 2004	PCBs, PAHs, TDBF Target volume – none specified Actual volume removed 85,655 yd^3	Freshwater; near shore area with outfall area; 21.8 acres dredged; dredging with cable arm buckets, derrick barge with fixed-boom mounted crane with GPS system; sheet pile system with herbicide application within system; silt curtains for select area; golf course water required for some areas	Low concentration sediments stabilized with cement and disposed of in facility landfill. High concentration sediments shipped and disposed of in hazardous waste facility	Some areas did not meet PCB cleanup goal. One failed area was backfilled to reach cleanup goal; some PAH cells were below cleanup goal and were not capped; low molecular weight PAHs would further break down to achieve goals

Table 6-2. Mechanical dredging case studies (continued)

Site	Contaminants/Targets	Site Description	Sediment Handling	Results
Hudson River, NY, 2009-present	PCBs SWAC Target volume 2.4M yd^3 Actual volume removed 660 K yd^3 (as of 2011)	Freshwater; 0-25 ft water depth; 43-mile stretch of river. Mechanical dredge with environmental bucket, silt curtains, cofferdams, dewatering system; 150,000 tons of backfill and caps	Contaminated sediment shipped to multiple off-site facilities; spoils sites covered with low-permeability soil caps	Dredging still ongoing
Starkweather Creek, WI, 1993	Hg, Pb, Cr, Oil, Grease Target volume 17,000 yd^3 Actual removed 15,000 yd^3	1.5-2 ft, sediment thickness 4-7 ft, area 1 mile x 50 ft; dredge depth up to 7 ft; wet excavation with backhoe; goal to increase depth from 4-7 ft Double silt curtains	Transported sediment to retention and dewatering facility off site and later disposed of	Goals met; no capping or backfilling required; no MNR

Table 6-2. Mechanical dredging case studies (continued)

Site	Contaminants/Targets	Site Description	Sediment Handling	Results
Ketchikan Pulp, AK, 2001	NH^3, sulfide, 4-methyl-phenol Target volume 20,550 yd^3 Actual removed volume 11,865 yd^3	Marine; 15-20 ft water depth; 80 acres within 250 acre cove; sediment thickness 3-10 ft; mechanical clamshell; 23,000 yd^3 within 30 acres backfilled/capped with sand	Contaminated sediments disposed of on site	Not specified but intended for protection of benthos
Sullivan's Ledge, MA, 2001	PCBs, PAHs Target volume-unspecified Actual volume removed 35,000 yd^3 in OU 2, OU 3. RG remove contaminated sediment	Brackish Marsh, no depth info; 80% debris content; OU 1 12 acres disposal area, stream and golf course water hazards. OU 2 7 acres wetlands in 25/100 yr floodplain; backhoes and long reach excavators; silt fencing, air monitoring	Removed sediments trucked to on-site treatment pad for stabilization. Contaminated material capped on site	Goals not met. Cleanup criterion determined to be unrealistic after sampling results

Table 6-2. Mechanical dredging case studies (continued)

Site	Contaminants/Targets	Site Description	Sediment Handling	Results
Ten Mile/Lange/Revere Canal, MI, 2003	Heavy metals, VOCs, SVOCs, PCBs Target volume unspecified; actual quantity removed 23,230 tons	Freshwater, 12-18 ft water depth; TMD system, catch basins, sanitary sewers, marina, sheet piles, silt curtains, dewatering systems	Contaminated sediments stabilized by bentonite-polymer mixture, off-site disposal to Wayne, MI, and Lenox, MI, disposal sites; canal soils sent to USACE site in Point Mouillee, MI	Goals met No capping, backfill required, Limited dredging in marina slips
Tennessee Product, TN, 1998	PAHs Target volume 5,000 yd^3 Actual volume removed 23,300 yd^3	Freshwater, 0-4 ft water depth; 2.5 miles x 50-75 ft width of Chattanooga Creek; floodplain disposal pit and coal tar area; earthen dams, pumping, long stick excavator used; NAPL capped site	Sediments mixed with drying agent, trucked to off-site disposal facilities, cement kiln in SC and TN, boiler in GA	No capping, backfilling required except for the NAPL site capped with Aquablok which is still being monitored

Table 6-2. Mechanical dredging case studies (continued)

Site	Contaminants/Targets	Site Description	Sediment Handling	Results
Terry Creek, GA , 2000	Toxaphene Mass removal of toxaphene Target volume 26,000 yd^3 Actual volume removed 35,148 yd^3	Freshwater; 900 ft outfall ditch, 2.2 acres of creek and confluent areas; environmental clamshell bucket, sheet piling	Sediments retained in drain beds for 6 months; dried sediments sent off site	Goals met with post removal concentrations

Table 6-3. Hydraulic dredging case studies

Site	Contaminants/Targets	Site Description	Sediment Handling	Results
Fox River/Green Bay, WI, 2002	PCBs, Hg, PAHs Target volume 92,000 yd^3 Actual removed 81,816 yd^3 SWAC	Project 1: Freshwater, 2-14 ft water depth; hydraulic auger dredging, followed by different dredging; silt curtains, sheet pilings; backfilled with sand	Dredged material to landfill; isolated in cell, monitored for leachate for life of landfill	Ineffective dredge replaced multiple times, different dredges used, 2 dredging passes, 1999-2000
Northern Deposit Fox River/Green Bay, WI, 1998	PCBs, Hg Target volume 12,000 yd^3 Actual removed 8,200 yd^3 RG mass removal, demonstration	Project 2: Freshwater, 0-8 ft water depth, contaminated sediment thickness 2-3 ft; Hydraulic cutterhead with swinging ladder; additional dredging at bedrock interface; perimeter barrier, silt curtain; turbidity meters; deflection barrier around industrial water intake	Sediments taken to county landfill; 1,632 tons to EQ landfill, 2,400 tons to disposal facility	Mixed results, PCB levels lowered in some areas, other areas post dredge levels higher that pre-dredge
Fox River Green Bay, WI, 2009	PCBs, Dioxin, Furan, DDT, heavy metals Target Volume 748,000 yd^3 Actual removed 500,000 yd^3 SWAC	OU 1: Freshwater, 6-20 ft; contaminated sediment area 39 miles, depth 1-6 ft; swinging ladder dredge used; silt curtains; sand cap	Non TSCA sediments transported to landfill	Goals met
DuPont, Gill Creek, 1992	VOCs, Hg, PCBs Target volume 40-3,400 yd^3 in select areas; riverbank unknown Actual removed 120-6,500 yd^3	Freshwater, 250 ft contaminated sediment area; hydraulic and mechanical dredging, and excavation; clay liner to prevent GW discharge; cofferdams, sandbags, dewatering systems used for excavation	Sediment stabilized with fly ash, transported to RCRA/TSCA landfill; hazardous sediments identified and incinerated	Goals met, lower levels, no backfilling required; 5-yr postremediation monitoring by sediment/water sampling

Table 6-3. Hydraulic dredging case studies (continued)

Site	Contaminants/Targets	Site Description	Sediment Handling	Results
GM Massena St Lawrence River NY, 1995	PCBs Target volume 29,000 yd^3 Actual removed 13,800 yd^3	Freshwater, St Lawrence River, flow rate 2.9 fps, 11 acres, 2,500 ft long near shore area; bottom boulders recycled to shore reconstruction; silt curtains replaced later by sheet pile	Highly contaminated sediments transported by rail to Utah facility; remaining sediments to lined on-site landfill	Goals met in 5/6 cells; augmented with sand backfill
Gould, Inc. East Doane Lake, OR, 1998	Pb, dioxin Target volume 6,000 yd^3 Actual removed 11,000 yd^3	Freshwater, debris contaminated lake, contaminant area 3.1 acres, 2 ft sediment depth; 1-5 ft dredge depth; horizontal dredge used; rock backfill	Sediments disposed of in on-site RCRA containment cell and later into constructed on-site landfill	Goals met with lower contaminant levels
Grand Calumet, IN, 2003	PAHs, PCBs, metals, cyanide Target volume 750,000 yd^3 Actual removed 788,000 yd^3 RG remove non-native sediments and contaminants	Freshwater, 0-4 ft water depth, 5 mile contaminated area, dredge depth 0-20 ft; floating debris boom, oil boom, turbidity curtain maintained 2,000-3,000 ft downstream, sheet pile system, cofferdams	Cofferdams to contain dredging areas over specified level; sediment deposited in on-site CAMU	Initial goals met but contaminant levels increased later; additional dredging required
Grand Calumet, IN, 2007	PCBs Target volume 24,000 yd^3 Actual volume 38,000 yd^3	Freshwater, 0-4 ft water depth, 63,000 ft river stretch	Sediment disposed in on-site landfill	Goals met after second dredging event when contaminant levels were above cleanup level

Table 6-3. Hydraulic dredging case studies (continued)

Site	Contaminants/Targets	Site Description	Sediment Handling	Results
Grasse River (hot-spot), NY, 1995	PCBs Target volume 3,500 yd^3 Actual removed 3,000 yd^3 SWAC	Freshwater, 10-15 ft depth, one acre near shore sediments; hydraulic auger with diver assisted vacuum, floating oil booms, silt curtains	Dredged slurry separated and treated with lime then filtered, disposed of in TSCA/RCRA landfill	Dredging difficulty due to bottom debris; higher post dredging fish tissue contaminant levels that later returned to pre-dredging levels; sediment sampling indicated that contaminant levels were reduced from surface to all depths; most of projected mass removed
Grasse River, NY, 2005	PCBs Target volume 75,000 yd^3 Actual removed 24,400 yd^3	Freshwater, 10-15 ft water depth; hydraulic cutterhead dredge, silt curtains, dewatering, Geotube system	Treated water returned to river, dewatered sediments disposed of in on-site TSCA/RCRA landfill	Pilot study for different capping materials; rocky bottom impeded progress and had equipment failures, limited dredging; after backfilling, 95% lower levels

Table 6-3. Hydraulic dredging case studies (continued)

Site	Contaminants/Targets	Site Description	Sediment Handling	Results
Gruber's Grove Bay, WI, 2001	Hg, methyl Hg, Cu, Pb Target volume 87,000 yd^3 Actual removed 88,300 yd^3	Freshwater, 2-18 ft water depth, 1-7 ft contaminated sediment thickness, area 18.2 acres; silt curtains, Geotubes	Dredged sediments placed into Geotubes, buried with clean soil cap cover	Uncertain, project completed with final corrective action, contaminant levels exceeded discharge permit
New Bedford, MA OU 1, 2004-present	PCBs Target volume 17,000-433,000 yd^3 Amendment with 867,000 yd^3.	Harbor, 6-50 ft water depth, silty sediments, 170-190 acres contaminated sediment area; salt marsh, residential, shipping channels; two hydraulic cutterhead dredges; silt curtains, 5 acre dewatering facility	Disposed of into 5 acre dewatering facility, 4 nearshore CDFs, slurry sent off site to TSCA facility by rail or truck	Silt curtains failed, replaced by BMPs, water quality measurements to ensure protective risk and continuation of ongoing dredging; PCB levels are lower
Petit Creek, Flume, NY, 1994	DNAPL Target volume 2,000 yd^3	Freshwater, river sediment, 1-acre cove area; diver assisted suction hydraulic dredging of grid sections; silt curtains, sheet pile system, cofferdams	Majority of sediments processed, placed into super sacks, remaining sediments disposed of into landfill	Post dredging sediment sampling indicated lower levels

Table 6-3. Hydraulic dredging case studies (continued)

Site	Contaminants/Targets	Site Description	Sediment Handling	Results
White Lake (OOC), MI, 2003	Cr, As, Hg, Tannery waste Target volume 76,000 yd^3 Actual removed 85,000 yd^3	Freshwater, 10-15 ft, 6.2 acres of bay; hydraulic cutterhead dredging, barge mounted excavator, silt curtains, dewatering system	Dewatering on barges and in Geotubes; sediments treated prior to disposal in off-site landfill; some dredged areas backfilled	Most tannery waste removed, post sampling residuals reduced
New Bedford, MA OU 2, 1995	PCBs, metals Target volume 10,000 yd^3 Actual removed 14,000 yd^3	5 acres contaminated sediment area; hydraulic cutterhead dredge modified with oil catching shroud; silt curtains	Dredged sediment were transported by pipeline to temporary CDF, dewatered and disposed of into off-site TSCA landfill	Goals met well below cleanup level
Outboard Marine Waukegan Harbor, IL, 1989	PCBs Target volume 10,900 - 35,700 yd^3 Actual removed 6,300 – 32,000 yd^3; SWAC	Freshwater harbor, 14-25 ft water depth, 10 acres of contaminated sediments; hydraulic cutterhead dredge; marina slip converted into on-site landfill; sheet pile system, silt curtains	Constructed on-site marina landfill sediments treated by thermal desorption; upper harbor sediments pumped directly into the marina landfill and water pumped out; the landfill was capped and vegetated	Goals met; silt curtains failure allowed suspended sediments to be treated with coagulant before silt curtain removal and upper harbor dredging completion; continued dredging in 2012, results unknown
Pegan Cove, MA OU 2 /Natick Labs / Army Natick Soldier Systems Center (NSSC), 2010	PCBs SWAC Target volume 2,510 yd^3	Freshwater, 0-10 ft water depth, shoreline, 34 acres contaminated sediments, SW outfall, 4 hotspots; hydraulic cutterhead dredge, silt curtains, water monitoring, dewatering systems (geotextile bags, pipeline)	Sediments pumped into geotextile bags; slurry pumped into dewatering stations; geotextile bags cut open, sediment trucked to off-site facility	Goals met, SWAC met; NFA

Table 6-3. Hydraulic dredging case studies (continued)

Site	Contaminants/Targets	Site Description	Sediment Handling	Results
Lavaca Bay, TX, 1999	Hg, PAH SWAC Target volume 184,000 yd^3 Actual removed 79,500 yd^3	Marine, bay, fringe marsh, 80,000 acre contaminated sediment area; hydraulic cutterhead dredge, silt curtain, turbidity monitoring, dewatering system	Contaminated sediment transported to off-site facility	Two phases were com-pleted, one implemented as treatability study, second as full-scale remediation; Hg levels elev-ated peri-odically; MNR to observe biota tissue level decreases
Pioneer Lake, OH, 1997	VOC, PAH, BTEX, Coal Tar Target volume 6,600 yd^3 Actual volume removed: 6,600 yd^3	Freshwater, gravel pit, lake sediment, sand, 0.5-3 ft sediment depth, 1 acre lake site, hydraulic cutterhead dredge, absorbent boom, silt curtains, settling basin	Phase 1: Nonhazardous sediments to landfill, nonhazardous sludge to city, Phase 2: coarse sediment to ECL, nonhazardous sludge to RDF, solid-ified sludge to treatment facility	Goals met, no capping needed

Table 6-4. Dredged material handling at sediment remediation sites

Site	Dredging Method	Volume Dredged Material	Disposal Location	Material Treatment	Material Regulated?	Transfer Method	Comments
Formosa Plastics, TX	Excavation	7,500 yd^3	Two off-site hazardous waste landfill; one 105 miles away, other 264 miles	Mixed with 10% cement to stabilize after partial dewatering	RCRA regulated	Truck	$1.4 million total cost, disposal rushed to meet deadlines, so two disposal facilities used and sediment stabilized with cement.
Lavaca Bay, TX	Hydraulic dredging	200,000 yd^3	on-site CDF on existing Dredge Island	No treatment	No	Direct Transfer	$3 million total cost
Messer St. MGP, NH	Hydraulic dredging and excavation	13,000 yd^3	2 hazardous waste disposal facilities. One 20 miles away, other 105 miles	Thermal desorption	Treatment allowed material to meet regulations of hazardous waste disposal facility	Truck	$13 million total cost; approximately $60/ton disposal cost, excess sediment treated at secondary landfill to save time
Fox River and Green Bay OU 1, WI	Swinging ladder hydraulic dredging	188,000 yd^3	off-site landfill approximately 20 miles away	Dewatering	Non-TSCA PCB waste	Truck	$61.7 million total cost
Gruber's Grove Bay, WI	Hydraulic dredging	88,000 yd^3	on-site CDF buried with top-soil	Dewatering with Geotubes	Non-regulated	Piping	$7 million total cost

Table 6-4. Dredged material handling at sediment remediation sites (continued)

Site	Dredging Method	Volume Dredged Material	Disposal Location	Material Treatment	Material Regulated?	Transfer Method	Comments
Ketchikan, AK	Mechanical dredging	11,865 yd^3	Adjacent industrial landfill	Gravity dewatering, water allowed to drain into ground	Material tested, found suitable for disposal in industrial landfill	Not mentioned	$1.8 million total cost, approximately $0.4 million for disposal
Housatonic River, MA	Excavation within sheet pile cells	6,000 yd^3 and 1,000 yd^3	Off-site commercial landfill	Gravity dewatering in stockpile	TSCA permitted landfill	Not mentioned	$4.5 million for first 6,000 yd^3
Bremerton Naval Complex, WA	Mechanical dredging	400,000 yd^3	CAD	Not needed	Testing after burial showed no contamination in water	Barge transfer, clamshell bucket for controlled placement	5 ft cap placed on CAD
Baird and McGuire, MA	Mechanical dredging	4,700 yd^3	On-site disposal	Incineration	No	Truck transfer to incinerator	Incinerated material returned to point of removal. Incinerator used for 210,000 tons of soil on site
Ashtabula River, OH	Hydraulic dredging	550,000 yd^3	Off-site CDF 3 miles away	Dewatering	CDF for the non-TSCA waste	3-mile pipeline	$50 million total cost

Table 6-4. Dredged material handling at sediment remediation sites (continued)

Site	Dredging Method	Volume Dredged Material	Disposal Location	Material Treatment	Material Regulated?	Transfer Method	Comments
Marathon Battery, NY	Hydraulic and mechanical dredging as well as excavation	100,000 yd^3	Off-site landfill in Michigan	Dewatering and stabilization	Stabilization allowed disposal to commercial sanitary landfill	Rail car	77,000 yd^3 dredged, 23,000 yd^3 excavated
United Heckathorn, CA	Mechanical dredging	108,000 yd^3	Two off-site landfills; one 871 miles away in AZ, the other 860 miles away in UT	Dewatering and stabilization	Stabilization allowed disposal to commercial solid waste landfill	Rail car	Cost for transport to landfill approximately $50 per ton
Reynolds, NY	Mechanical Dredging	85,600 yd^3	Majority to on-site CDF, remainder to off-site disposal 325 miles away	Stabilization with Portland cement for CDF	TSCA regulated PCB waste to authorized hazardous waste facility	Truck	69,000 yd^3 disposed on site, 16,600 yd^3disposed off site

7.0 MONITORING

Monitoring data collected before, during, and after remediation provide an objective basis for evaluating remedy performance and effectiveness. Monitoring data are used for gauging progress towards meeting the RAOs and determining whether further remediation or a change to the current remedy is required. The technologies addressed in this guidance document (MNR/EMNR, in situ treatment, capping, and removal) all require monitoring at various stages of implementation.

Monitoring is part of the planning process from the earliest phases of the project. Typically, a thorough site investigation (for example, an RI) is performed as part of the process for developing a CSM, defining RAOs, and selecting a remedial action alternative. The RI is normally comprehensive; however, RI data may require supplementation to define the metrics that are used to assess the long-term effectiveness of the selected remedy. In most cases, multiple lines of evidence are used to determine the remedy success, regardless of whether the alternative includes dredging, capping, or MNR. Data from a variety of physical, chemical, and biological processes may be required to establish the metrics. Sediment deposition, resuspension, and movement can complicate data interpretation, even for well-designed sediment monitoring programs. Adequate samples upgradient and downgradient of the area of interest aid in interpreting the monitoring data and understanding the processes that occur over the life of the monitoring program.

7.1 Types of Monitoring

Three basic types of monitoring related to sediment remediation are discussed in this chapter:

- baseline
- construction
- post-remediation

Baseline monitoring is performed prior to a remedial action to assess the conditions at the site prior to construction or prior to formal monitoring when demonstrating MNR. Baseline monitoring differs from site characterization in that not all measurements needed to characterize a site are carried forward in the monitoring program. The design for baseline monitoring is best completed after the characterization has determined the physical, chemical, or biological conditions to be measured later, the zones to be included in the monitoring design, and a consistent set of variables to be characterized throughout the monitoring program.

> ***USEPA Monitoring***
>
> *Monitoring should be conducted at most contaminated sediment sites for a variety of reasons, including: 1) to assess compliance with design and performance standards; 2) to assess short-term remedy performance and effectiveness in meeting sediment cleanup levels; and/or 3) to evaluate long-term remedy effectiveness in achieving RAOs and in reducing human health and/or environmental risk. In addition, monitoring data are usually needed to complete the five-year review process where such a review is necessary (USEPA 2005, Chapter 8).*

Construction monitoring typically occurs during or immediately following implementation of the remedy and indicates whether the remedy has achieved design criteria (such as specifications for cap thickness, dredging depth, turbidity limits, sedimentation rates, water quality criteria, and perhaps resuspension levels). The construction monitoring plan must be strictly followed in order to evaluate compliance with design specifications. For example, improper placement of downstream particulate monitoring equipment during remedy construction could lead to erroneous conclusions regarding resuspension of sediments. Construction monitoring does not apply to sites where MNR has been selected as the remedy.

Post-remediation monitoring (sometimes referred to as long-term monitoring) takes place following implementation of the remedy and continues until the remedy has met the established goals. There are two types of post-remediation monitoring: performance monitoring and effectiveness monitoring. Performance monitoring indicates whether the remedy has met or is approaching the goals on a zone-by-zone basis (for example, to determine the physical integrity of a cap or sedimentation rates for MNR). Effectiveness monitoring focuses on whether the remedial action achieved the overall RAOs. Effectiveness monitoring is typically designed to determine whether the remedy has achieved the RAOs by analyzing fish tissue, benthic tissue, or other indicators of remedy success. Figure 7-1 describes sediment remediation monitoring programs.

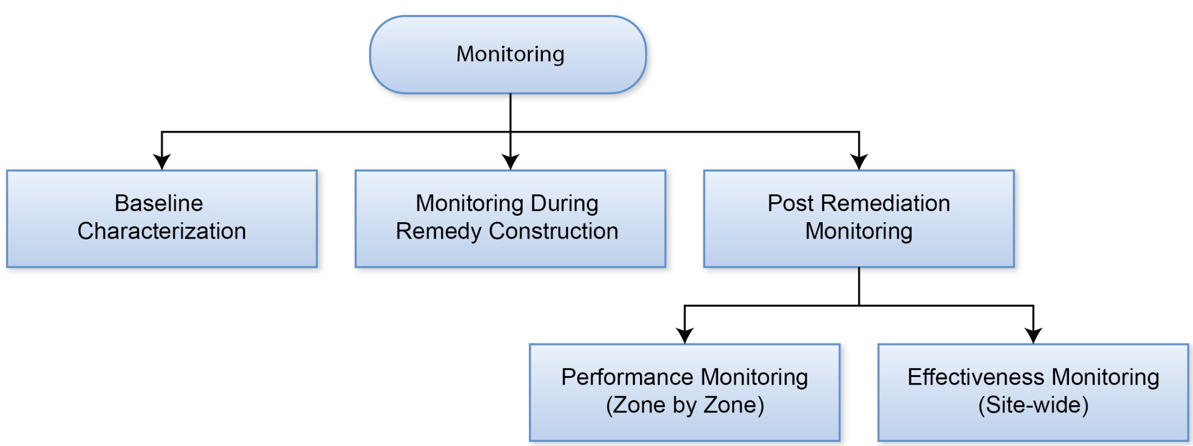


Figure 7-1. Sediment remediation monitoring programs.

7.2 Developing a Monitoring Plan

Several guidance documents are available to help project managers develop monitoring plans for sediment remediation efforts. In particular, Chapter 8 of USEPA's guidance (2005a) applies to monitoring plans at sediment sites. USEPA (2005a) addresses remedial action and long-term monitoring and describes a six-step process for developing and implementing a monitoring plan. For sites that require a sediment cap, USEPA's Great Lakes National Program Office capping guidance (Palermo 1998) presents extensive guidance on monitoring. The Great Lakes guide presents a five-step process that is similar to the USEPA 2005 process. Another guide, *Implementation Guide for Assessing and Managing Contaminated Sediment at Navy Facilities* (NAVFAC 2003b) contains information on design and implementation of monitoring plans for contaminated sediment management programs. Monitoring considerations discussed include: (a) spatial trends in dynamic systems; (b) co-occurrence between sediment contaminant concentrations, toxicity, and bioaccumulation; and (c) geochemical normalizers in data interpretation. The Navy has also issued a guide entitled *Long-Term Monitoring Strategies for Contaminated Sediment Management* (SPAWAR 2010), which emphasizes the need to define an exit strategy as part of the monitoring plan. The Navy also developed the *Technical Guidance on Monitored Natural Recovery at Contaminated Sediment Sites* (NAVFAC 2009) and U.S. Navy-SPAWAR (ESTCP Project ER-0622), which provide information on the design of monitoring programs. Another useful guide, *Monitored Natural Recovery at Contaminated Sediment Sites* (Magar et al. 2009), was developed under the auspices of the Environmental Security Technology Certification Program (ESTCP). This document discusses the lines of evidence used for assessing MNR and the baseline and long-term monitoring approaches to be used in the evaluation process.

Planning for Monitoring Programs

- *Establish monitoring objectives.*
- *Determine measures needed to satisfy monitoring objectives.*
- *Define sampling units and monitoring boundaries.*
- *Specify how data will be used to satisfy the objectives.*
- *Consider uncertainty.*
- *Design the monitoring program.*

The following section describes a process to develop an effective monitoring plan that incorporates USEPA's systematic planning process, known as the Data Quality Objectives Process. This guidance emphasizes the development of a complete set of specifications for the design of a monitoring program to maximize the probability that data collected is adequate to draw conclusions regarding whether remedy performance and effectiveness criteria are being met. This process results in a desired degree of confidence and requires that the statistical analysis parameters are identified early in the planning process. Monitoring program considerations specific to remediation of contaminated sediment sites include:

- evaluation of spatial trends over time in dynamic systems altered by remedial action
- monitoring for changes in co-occurrence of sediment contaminant concentrations, toxicity, and bioaccumulation in dynamic systems altered by remedial actions
- monitoring for biological elements and geochemical normalizing elements critical to data interpretation in complex sediment systems altered by remedial actions

7.3 Planning Monitoring Programs

When planning a sediment remediation monitoring program, the CSM should be periodically revisited and updated. Previous contaminant source, pathway, and receptor elements may change upon implementation of the remedy if differing site conditions are encountered during construction. The monitoring plan should include contingencies and be flexible enough to adapt to changing circumstances. The monitoring program should be designed using results from site characterization and pre-design studies to address site-specific considerations.

7.3.1 Establish Monitoring Program Objectives, Questions, Decision Points, and Time Frames

Monitoring program objectives, questions, decision points, and time frames should be established prior to any detailed consideration of what to measure, how often or where to measure, or how long to measure a particular parameter. When defining objectives, avoid open-ended statements (such as "to determine whether the remedy is working") and instead describe measurable objectives, questions, and decision points. Consider SMART (specific, measurable, attainable, relevant, and time bound) criteria when formulating objectives. Sediment remediation monitoring program objectives should address the three main types of monitoring shown in Figure 7-1.

Separate objectives must be developed for each type or phase of monitoring. An effective way to clearly convey the objectives of the monitoring program is to identify and state the specific questions that must be answered in order to achieve the objectives. If subordinate questions are tied to specific measurements needed to address the higher level questions, consider organizing these questions in a logical hierarchy so that the relationship between questions is clear. The results of monitoring answer the questions that may be used to support a decision about what course of action to take (for example, to change remedial technologies or move from MNR to an active remediation alternative). A decision statement should be developed to explain clearly what finding will lead to the action. A flowchart constructed to diagram the sequencing and to depict alternative pathways leading to all possible outcomes can be helpful. Examples of these time lines to depict monitoring phase sequencing are shown in Figures 3.1, Figure 3.2, and Figure 3.3 in SPAWAR (2010).

The objective of baseline characterization is to determine the conditions such as average concentration and distribution of contaminants and other parameters of interest in each zone prior to remedy implementation. If the environmental problem reflects seasonally dynamic variations (such as methyl mercury production or sedimentation rates), then baseline characterization must represent the seasonal variations. For example, avoid comparing winter results to summer summer results, or high precipitation seasons compared to dry seasons. These comparisons can result in incorrect conclusions that reflect seasonal effects rather than remedy effectiveness.

Ideally, long-term monitoring is considered during site characterization. Data representative of baseline (pre-remedy) conditions and background (data from upgradient, upstream, or reference locations) should be collected as part of the RI or similar site characterization efforts. For some sites, however, additional baseline considerations are required to obtain measurements of variables that were not previously collected or to provide spatial or temporal coverage. For example, at large complex sites, it may be necessary to assess different zones (Section 2.9) to ensure that baseline conditions are established for each zone. Each zone would then be monitored to evaluate the implementation and post-remedy conditions within that zone, with RAOs established for that zone.

The objective of monitoring during remedy implementation is to determine whether the established design criteria are being met. For example, for hydraulic dredging, the relevant questions may be:

- Is resuspension adequately controlled?
- Are water quality criteria being achieved during remediation?
- Are curtains or other barriers used to control the migration of resuspended materials functioning as designed?

If capping is the primary remedy, the relevant questions may be:

- Has the required thickness of cap material been achieved?
- Are there exceedances of water quality criteria?
- Are unacceptable concentrations of contaminated sediment being resuspended?

Corrective measures, if necessary, can then be implemented. Similarly, for MNR a relevant question could be:

- Are upstream suspended solids loads remaining consistent with baseline conditions?

The time frame for monitoring must be established. For example, sampling may be required during, and a few days following, capping to determine whether resuspended sediment and water quality stabilizes. Physical changes can be measured immediately following the remedy (for example, did dredging remove the planned depth, or was a cap of a specified thickness emplaced?). Biological measures, however, may require a longer time frame before meaningful changes can be observed.

Objectives related to post-remediation monitoring are established to determine whether the remedy is achieving the RAOs. Often, short- and long-term objectives relate to the measurable performance of the remedy on a zone-by-zone basis, and the effectiveness of the remedy for the site in general over time. For example:

- A short-term post-remediation performance-monitoring objective may be to determine whether the remedy has successfully reduced concentrations of COCs in sediment to acceptable levels and whether specific parameters (such as cap thickness or dredge depth) have been achieved.
- A long-term monitoring objective for post-remediation effectiveness may be to determine whether concentrations of COCs in affected media continue to meet RAOs, or display a decreasing trend expected to meet RAOs in an acceptable time frame. RAOs may include recovery and sustainability of the site habitat, which may build upon recovery of a watershed. Additionally, the objectives for MNR may include a demonstration that burial rates and compound degradation or transformations are occurring as projected and tissue levels continue to show acceptable improvement.

Monitoring must be tailored to the specifics of the site. Several examples of short- and long-term questions are shown below:

- Short-term question:
  - Do the mean sediment and water concentrations of COCs within specific zones at the site meet the RAOs?

- Long-term questions where dredging or MNR is used:
  - Are there remaining zones with concentrations of COCs that exceed applicable RAOs?
  - Is continued sedimentation decreasing surface sediment concentrations of COCs?
  - Is there evidence of further natural recovery occurring?

- Capping performance questions:
  - Are the integrity and thickness of the cap maintained over time?
  - Are contaminants migrating upward through the cap material?

- Site effectiveness questions:
  - Are concentrations of COCs in fish tissue above levels protective of human or ecological receptors?
  - Are concentrations of contaminants in fish tissue changing over time?

For each question a specific, testable hypothesis can be stated. For example, a short-term hypothesis (post-remediation) may be:

- Have the concentrations of COCs within a zone reached their RAOs (numerical clean- up criteria) in surface sediment and water?

Stating the null hypothesis as having achieved the goal is appropriate, since that is expected to be true after remediation. This approach leads to a statistical test that requires the data to demonstrate that the site continues to be "dirty" (to reject the null as stated above, that the site is now "clean"). Similar testable hypotheses should be developed for each secondary question and the design of the monitoring program should ensure adequate data to test each stated hypothesis.

7.3.2 Determine Measures Needed to Satisfy Monitoring Program Objectives

With established monitoring objectives, the next step is to determine what measurements or other information is needed. The goal is to derive the most cost-effective design that will meet the objectives.

Depending on the objectives, monitoring may include:

- physical properties measurements (flow rate, particle size, temperature, wind direction, and sedimentation rates)
- chemical measurements of the matrix or media being studied (concentrations of chemicals in specific media such as surface water, pore water, water entering or leaving the system, surface sediment, subsurface sediment, and the matrix or media being studied in the hyporheic zone)
- concentrations of COCs in plants or in biotic tissues or organs of fish, shellfish, crustaceans, mollusks, worms, and other resident communities
- biological measurements (type, number, and diversity of organisms present)
- bioassays, geochemical and physiochemical tests to examine biological, chemical, or ecological effects

The source of data is important. For existing information locate QA/QC and other metadata, including location, depth and date of samples, sample collection method, and sample analysis methods. This supporting information establishes the reliability of the data and may indicate any limitations associated with its use.

For new data, establish the methods available for obtaining the information, including the sample collection method and analytical methods. When chemical measurements are required, the target analytes or COCs must be included. For each analyte, the concentration level at which it is important to obtain quantitative measurements should be stipulated. This information can then be used to determine whether analytical methods are available that can provide measurements at or below the required levels and can be used to evaluate the suitability of existing data sources.

Standard methods that provide measurements of an analyte class may be appropriate. If these standard methods are incapable of achieving the required detection limits, or existing data sets have detection limits above levels of interest, an alternate method of monitoring the system may be appropriate. When multiple methods with adequate detection limits are available, compare the analytical performance of each method such as PARCCS (precision, accuracy, representativeness, comparability, completeness and sensitivity), cost, availability, and turnaround time.

To establish the relevance of each measurement to the objective, assemble the monitoring parameters, performance expectations, and analytical methods in a matrix. Then, list the study questions as a series of columns and each of the individual inputs as a series of rows. The level of detail may vary from associating study questions with broad categories of information (such as concentrations of semi-volatile constituents in sediment) using a simple check mark, to a more detailed analysis such as denoting individual constituents and completing the cells in the matrix with the thresholds for each constituent that the measurement methods must be able to detect. If it is not clear what question a measurement will be used to answer, then consider deleting the measurement. While measurements may not necessarily add to the cost of sampling and analysis, they may add to the cost of data validation, maintenance of the database, and data interpretation and analysis.

For many sediment sites, numerical criteria (such as cleanup levels) may be established. Alternatively, monitoring data may be compared to other measurements obtained for the project (for instance, comparing information for one area or point in time to that for another area or point in time). For projects involving characterization of on-site conditions and comparison to upgradient or background conditions, discrete data sets may be required to clarify conditions in upgradient or background populations.

Technology-specific monitoring parameters and approaches for baseline, construction, and post-remediation monitoring are discussed in each technology overview.

- MNR/EMNR, Section 3.6
- In situ treatment, Section 4.6
- Capping (conventional and amended), Section 5.6
- Removal, dredging (hydraulic and mechanical) and excavation, Section 6.6

Note that measurements that are used to establish remedy performance and effectiveness should be clearly defined and characterized prior to remedy implementation. These measurements establish a before-and-after comparison to evaluate remedial action effectiveness in achieving RAOs.

7.3.3 Define Sampling Units and Monitoring Boundaries

The boundaries for the monitoring program must be documented. Clearly define where, when, and what monitoring measurements must be obtained. Maps, pictures, or descriptions should clearly depict what portion of the environment or what set of conditions the monitoring effort is intended to represent, and identify the time frame necessary. Within zones (Section 2.5), a map should illustrate site conditions that influence the selection of remedial technologies (such as horizontal and lateral COC distribution, bathymetry, sediment stability, sediment deposition rates, hydrodynamics, and others; see Table 2-2). For many sediment monitoring programs, data or information will be needed to understand conditions in three dimensions. In these cases, specify the boundaries for each. For example, if data will be needed to represent different layers of sediment or water, specify boundaries for each of those dimensions. By displaying these boundaries on maps, it is possible to show how data points represent the areas of interest. The map, picture, or description establishes boundaries on a large scale, while the sampling plans focus on the number and allocation of samples within these boundaries that are necessary to adequately represent the conditions in the area.

Sampling units can be defined as the portion of the physical environment from which one or more samples may be taken to obtain measurements appropriate for the intended use. For samples of water, sediment, fish, or other organisms, these units can be defined to be as small as the dimensions of an individual sample, or can be defined to represent larger areas that encompass multiple samples including composites. Sampling units can be intervals of time (such as weekly average surface water concentrations). Multiple considerations based on sampling theory can be used to establish the actual dimensions of a sampling unit and, when appropriate, these considerations can be addressed during the design of the study. For existing data sets, unless metadata are available that discuss the dimensions of sampling units, it may be necessary to assume the sampling unit is simply the dimensions of the sample itself. If a list of sampling units can be identified, then it should be included and the basis for the list provided.

If the monitoring project is expected to support decisions at a scale smaller than the overall study boundaries (sometimes referred to as the scale of inference), the boundaries for these decision units should be specified. For example, if a study is designed to represent the entire site but decision makers want to be able to generate estimates for, and make separate decisions about (or compare) each zone within the site, it must be clearly stated. It may be important to define zones based on characteristics such as grain size or depositional environment to avoid comparisons of concentrations between fine grain clays and silts and coarse sands. Defining multiple decision units can affect the design and may influence the adequacy of existing data sets. A study design adequate to answer questions about the entire site with an acceptable degree of certainty may not be adequate to answer questions on individual portions of that area or individual time periods.

During remedy construction monitoring, it is important to specify what the samples are intended to represent so as to avoid improper placement of monitoring equipment (such as down stream particulate monitoring stations). If incorrect boundaries are selected, then samples taken to represent the areas of interest may lead to incorrect conclusions about the effects of placing the cap or performing dredging.

For many projects, it is equally important to establish and document temporal boundaries that specify the particular time frame the project is intended to represent. For dynamic media such as outfalls, streams, or rivers, temporal boundaries may stipulate specific conditions or periods of time that measurements must represent. For example, a monitoring program designed to sample after a specified event such as a flood, storm, or river level may suggest a potential effect on the integrity of a cap. For remedial alternatives that may result in a temporary increase in available contaminants (such as through resuspension), the length of time that will be necessary for meaningful results (such as decreases in tissue concentration) may require that temporal boundaries be incorporated into the design of the monitoring effort.

7.3.4 Specify How Measurements Will be Used to Satisfy the Objectives

To ensure that an efficient and effective monitoring program is established, take the time to document how each measurement will be used to answer one or more of the subordinate or primary questions. Be as specific as possible—indicate whether data will be used to estimate a mean value for a zone or time period, or some other measurement parameter. For results used to decide upon a course of action, a simple if-then decision rule can be formulated, with the "if" part being the conditions represented by monitoring (such as the mean concentrations, or the estimated rate of reduction of the mean concentration over some time-frame) and the "then" part representing the course of action to be taken.

For measurements that are not readily linked to a question, if it is possible to explain how they may be useful (such as in data interpretation or trend analysis), a determination can be made as to whether to include them in the design or not.

7.3.5 Specify Desired Level of Certainty

For monitoring programs, it is important to state the level of confidence required to discern changes of a specified magnitude (based on the expected behavior of the remedy). Together with an estimate of the expected variability in the data results, this level of confidence directly influences the number of samples that will be needed. The confidence level is one key to understanding the variability associated with the rate of change for a particular process, such as a decline in tissue concentrations that occurs after the remedy is implemented. Whether the remedy includes dredging, capping, MNR, or a combination of these remedies, the variability in the system determines the level of confidence that the remedy will meet the RAOs. Projecting the remedy success and potential need for future remedial measures depends upon a reliable baseline that describes the nature of site variability. USEPA’s DQO guidance (2006b) discusses the process of setting performance criteria and recognizes that establishing performance criteria can be done in a number of ways. While it is desirable to identify quantitative limits on uncertainty, a graded approach to this quantification can focus specifications on the most critical metrics, while leaving the other metrics more qualitative.

7.3.6 Design the Monitoring Program

When practical, a statistical design should be used to support the selection of the most efficient monitoring program for assessing whether the objectives are being met. Baseline data can be used to estimate the variability of the various metrics of interest. An estimate of the variance, along with the specifications for uncertainty and magnitude of change that is important to detect, can be used to generate a sample size for the monitoring program. Working with a project team (including a design statistician for more complex programs), the sample size (frequency and number of samples per sampling event) can be selected. A design team can evaluate the use of compositing and other efficient sampling methods in order to arrive at design alternatives that generate data of adequate quality to discern changes over time. The data quality and statistical aspects of monitoring design are beyond the scope of this guidance; however, the methods used must be defensible and the analysis presented clearly.

7.4 Additional Resources

Several existing guidance documents provide discussions of monitoring concepts and program design considerations for contaminated sediment sites:

- *Guidance for Environmental Background Analysis, Volume II: Sediment. Naval Facilities Engineering Command, NFESC Users Guide* (NAVFAC 2003a)
- *Environmental Security Technology Certification Program Monitored Natural Recovery at Contaminated Sediment Sites* (ESTCP 2009).
- *Laboratory Detection Limits and Reporting Issues Related to Risk Assessment* (NAVFAC 2002)
- *Determination of Sediment PAH Bioavailability Using Direct Pore Water Analysis by Solid-Phase Microextraction* (ESTCP 2010)
- *Sediment Bioavailability Initiative: Development of Standard Methods and Approaches for the Use of Passive Samplers in Assessing and Managing Contaminated Sediments* (ESTCP 2012-2014)
- *Demonstration and Commercialization of the Sediment Ecosystem Assessment Protocol (SEAP)* (ESTCP 2012-2014)
- *National Coastal Assessment Field Operations Manual* (USEPA 2001)
- *Environmental Monitoring and Assessment Program (EMAP): Great River Ecosystems, Field Operations Manual* (USEPA 2006c)
- *Incorporating Bioavailability Considerations into the Evaluation of Contaminated Sediment Sites* (ITRC 2011)
- *Guidance on Data Quality Assurance, Data Quality Objectives, Data Assessment, and Data Validation* (USEPA 2006f)
- *Requirements for Quality Assurance Project Plans* (USEPA 2006d)
- *Guidance on Systematic Planning Using the Data Quality Objectives Process* (USEPA 2006e)
- *Technical Guide, Monitored Natural Recovery at Contaminated Sediment Sites* (Magar et al. 2009)

8.0 COMMUNITY AND TRIBAL STAKEHOLDER CONCERNS AND ECONOMIC CONSIDERATIONS

The selection of an appropriate sediment remedy directly affects the welfare of the community whose environment, public health, and economy may have been affected by sediment contamination. At many sites, a simple risk reduction may not be sufficient to protect human health and the environment because sites must also comply with the full complement of water law and public trust principles in order to maintain a sustainable and productive resource. The relationship between remedial technologies and the laws and regulations that apply to sediment sites can complicate site cleanup. Both stakeholders and regulated parties should understand the technologies and the regulations in order to select remedies that are acceptable to all who share water resources. This understanding is of special importance for tribal lands because additional tribal agreements must be considered when developing sediment cleanup RAOs for habitat and watershed use.

A sediment remedy must protect public resources for all who depend on these resources. Clean sediments provide the base for regional ecosystems that supply food to aquatic organisms, wildlife, and people. A clean sediment environment is equally important for economic, recreational, and subsistence fishing for tribal and community health. Significant stakeholder and tribal concerns exist that are unique to contaminated sediment remediation because of these effects on surface water and sediment resources. Communicating with stakeholders early in the remedial process helps to develop a shared, resource-driven discussion and form a cooperative basis for remedy selection and implementation.

8.1 Regulatory Framework and Public Trust Doctrine

Under the Public Trust Doctrine (PTD), state governments must manage and protect certain natural resources for the sole benefit of their citizens, both current and future. The National Pollutant Discharge Elimination System (NPDES) is one of many examples of how the science behind watershed management works to achieve the goals and principles that form the basis of the PTD model for protection and management of water resources. The science that drives watershed management principles for multiple sources of contaminated sediment is similar to that for setting limits on chemical discharges from municipal or industrial treatment plants. The cumulative effect of sediment sources of contamination in the watershed can have the same detrimental effect as too much loading from municipal or industrial facilities, and thus should be managed using similar principles.

Public Trust Doctrine

"Upon independence from Britain, public lands and waters and a law that would become a foundational principle of American natural resources policy became vested in the nascent state governments. Under the public trust doctrine (PTD), state governments must manage and protect certain natural resources for the sole benefit of their citizens, both current and future. This principle has been enforced in courts, canonized in state constitutions, and is at the heart of

> *many states' fisheries, wildlife, and water laws. Suggesting, "[p]ublic trust law lies in the deep background of most environmental cases, and at the cutting edge of many," some scholars have gone so far as to call the PTD the "conceptual and spiritual compass" of environmental law. Today, there are 50 state PTDs, intimations of a federal PTD, and the doctrine has also increasingly appeared in legal systems outside of the United States."*
>
> *—from "Reinvigorating the Public Trust Doctrine: Expert Opinion on the Potential of a Public trust Mandate in U.S. and International Environmental Law" (Turnipseed et al. 2010).*

Much of the world's population lives in or near watersheds, and thus is affected by the sustainability of these watersheds. In a 2000 report, the World Resources Institute stated the following: "…in 1995, over 2.2 billion people—39 percent of the world's population—lived within 100 km of a coast, an increase from 2 billion people in 1990. The coastal area accounts for only 20 percent of all land area" (WRI 2000). According to 2002 data from the National Oceanic and Atmospheric Administration, over 50% of people in the United States live within 50 miles of an ocean or Great Lake. Clearly, major population centers at risk of food chain exposure from bioaccumulatives, endocrine disruptors, and other risks are in proximity to surface waters, and by association, sediment sites. Sediment sites are often literally in the backyards of stakeholders and, because of the relatively high mobility of sediments and some contaminants, these sites may expand farther downstream into other larger watersheds and into more accessible private and public property resources.

Management of these public resources has always been in the public trust arena; however, this public trust is not always recognized as the foundation of management decisions for specific sites. Therefore, oversight agencies, as well as the responsible party facilitating the cleanup, must conduct the remedial investigation, development of RAOs, FS, and remedy selection and design with the public resource concept at the core of decision making. This approach reminds both the regulated community and the interested stakeholders that they are operating under a complement of existing laws clearly designed and developed for the welfare of the public.

8.2 Tribal Concerns

Many general stakeholder concerns are also relevant to tribal lands and water resources. Tribal lands include the reservation land base as well as ceded and usual and accustomed areas (CUAAs), which are lands that are co-managed under both tribal and federal jurisdiction based on court decisions and cooperative agreements. The natural resource base of tribal and CUAA lands is about 135 million acres, or almost 211,000 square miles. This area contains more than 730,000 acres of lakes and reservoirs and over 10,000 miles of streams and rivers. Numerous treaties between the U.S. government and Native American tribes guarantee complete sovereignty to the tribes for these lands and natural resources. Currently, many tribes are asserting their treaty rights to manage their fish and wildlife resources, but most tribes lack the funding and human resources necessary to adequately manage these resources.

Generally, both statutory and tribal management practices require a watershed and regional perspective to manage the resources for the benefit of those who use the resources. The welfare and protection of water resources from a state and national perspective are considered a matter of public trust. The PTD holds that these resources should be sustained and made available for current and future generations. The Native American perspective toward contaminated sediment remediation varies among tribes depending on their location, climate, natural resources, and culture. Certain central tenets, however, hold true across all tribal lands in regard to pollution of natural resources. Native American cultural and spiritual values pertaining to the environment differ from those of mainstream U.S. society. Clean water and unpolluted waterways are of paramount importance to tribal societies, especially those that depend on subsistence fishing and hunting. Even in tribes that are not subsistence societies, a clean natural environment is considered a sacred responsibility and held in highest honor.

Contaminated sediments have the potential to damage public and tribal resources, thus regional watershed management is an integral part of sediment remedy selection discussions with stakeholders and regulators. Multiple sediment site effects on the health of local or regional watersheds are a component of decisions, because the entire resource may be held in public trust or tribal sacredness. These concerns align with the concerns of stakeholders who wish to protect these resources for current and future use. The PTD and regulations for management of resources for the benefit of the citizens are based on the same principle: to protect the public health and environment for the good of the citizens and to sustain resources for future generations.

8.3 Costs for Regional Economies

Significant national economic interests rely on aquatic resources that may be affected by contaminated sediments. As a result, recreational opportunities, cultural issues, property values, tribal fishing rights and treaties, reproductive habitat, and regional economies based on consumption of noncontaminated freshwater and saltwater species become important stakeholder concerns.

8.3.1 Bioaccumulatives and Endocrine Disruptor Costs

Because of their mobility, contaminated sediment sites are in the public resource arena and should be addressed on a regional basis, especially if bioaccumulatives and endocrine disruptors are present in the food chain and watershed. The release of bioaccumulatives and endocrine disruptors to the environment through long-term leaching from contaminated sediment can affect the health of those using the watershed. The cost of chronic health care issues and potential birth defects due to these compounds must be discussed with stakeholders. Sediment cleanup to levels that are developed to protect human health and the environment when these compounds are present will directly affect the selection of an appropriate remedial technology and its associated costs.

Costs are also associated with only addressing risk, while not improving habitat, restoring recreational opportunities, or expediting the elimination of fish advisories for bioaccumulatives from entire regions. The Great Lakes hold 22% of the world’s fresh water resources, and currently fish consumption advisories are placed on all five of the Great Lakes. The same endocrine disruptors and bioaccumulative substances that have resulted in the Great Lakes advisories also exist in Gulf Coast estuaries, many coastal and inland wetlands, regional watershed ecosystems such as the Chesapeake Bay, and many inland lakes and streams that feed the tributaries that discharge to the East, West, and Gulf Coasts.

8.3.2 Risk Management and Monitoring Costs

Risks associated with contaminated sediments differ from risks that can be controlled on private upland industrial property or public property. Upland sites can often be visually monitored through frequent inspections. Many of the chemicals in sediment, however, are soluble (and therefore mobile) and subject to extreme drought and weather events that flood, dry, and eventually redistribute the contaminants. The physical setting, the science of short- and long-term contaminant transport, and the sediment mobility make visual monitoring cost prohibitive or technically impossible for most sediment sites.

Risk management is more challenging in sediments than at upland sites. Engineering and design assumptions may not always account for the effects of extreme storm events and drought conditions followed by flooding, which can completely or partially redistribute massive quantities of contamination. Redistribution of chemicals buried at depth and thus assumed to be in a stable environment are of greater concern under these conditions.

8.3.3 Funding Cleanups for Government and Tribal Sites

The cost of sediment remediation to federal, state, and local governments and tribes who also have obligations to fund human health and social mandates is a concern to stakeholders. These direct needs must be balanced with the quality of life and health of the regional population and environment that are affected by the contaminated site. Government and tribal entities fund cleanup of contamination that has become their obligation due to bankruptcy, default, or poor environmental practices from the past century. These legacy problems are difficult because it is sometimes impossible to determine which parties are responsible for the contamination.

Native American tribes vary widely in their ability to finance and manage environmental programs. For example, one tribal nation in the southeast United States is aware of lead and mercury contamination in their riparian and lake sediments, but does not have funds to conduct a site characterization and develop baseline data, much less to undertake remediation. Conversely, a large tribal nation in the southwest United States has a fully staffed Division of Natural Resources within its tribal government. Yet another tribal federation in northeast United States had the resources to use stable isotope analysis to identify a near-by smelter as the source of contamination of tribal water resources and sediments and is negotiating with the smelter for future remedial action.

Most tribes desire to be good stewards of the environment, but realize that financial resources for such efforts are scarce. Because a high percentage of reservation inhabitants live below the poverty line, many tribal governments fund health and social services as their highest priority and then struggle to find funds for other programs such as sediment remediation. Grant money, although helpful for short-term projects, does not provide the long-term support necessary to develop environmental programs and to retain a trained technical staff. Consequently, more costly technologies to remediate contaminated sediments are not likely to be used extensively on most tribal lands. Another challenge is the difficulty in obtaining access to some tribal lands for making improvements.

8.4 Habitat Restoration and Preservation

Aquatic habitat restoration is a component of remedy discussions that should occur with stakeholders and tribes prior to any decision involving a remediation technology. Preventing destruction and maintaining habitat for both terrestrial and aquatic environments are important from a regulatory as well as stakeholder perspective. This concern is not always adequately represented by resource agencies that may invoke natural resource damages claims. Stakeholders should be apprised of these discussions before remedial decisions are made in order to be certain that their concerns for local and regional watersheds are represented.

The need for habitat restoration is based upon strong supporting scientific research and restoration is usually supported by stakeholders. Each technology in this guidance should be presented to the stakeholders to assess restoration benefits and then evaluated by the stakeholders to determine how effective the technology will be with respect to restoration of habitat. These discussions should occur with stakeholders when developing RAOs, as well as during the remedy selection process.

The nation's fisheries and aquatic-based environment depend on the high-quality sediment resources necessary to provide healthy populations of aquatic organisms that support the food chain—the foundation of the regional ecosystem. Restoration and sustainability of the hyporheic zone (see Section 8.5) are necessary to maintain critical habitat and to sustain the health of the entire watershed (see Ground Water and Surface Water: A Single Resource, USGS 1998). The hyporheic zone often is the base for entire aquatic ecosystems in watersheds that have interaction with groundwater and surface water. The value of remedial activities for this zone should also be communicated to stakeholders early in the decision-making process.

The habitat generated by the interaction of saltwater, brackish water, and freshwater in the rivers and estuaries of the Gulf, East, and Pacific coasts are essential for species that reside in these ecosystems. Thus restoration and preservation of this zone of interaction is of great importance. Most, if not all, of the geochemical and biological characteristics of these zones are necessary to maintain the habitat, spawning and fisheries health, and the aquatic and terrestrial ecosystems.

Although habitat restoration is important, responsible parties may only be responsible for areas that they have affected, and complete restoration may not always be achievable. Stakeholders should be made aware of what is realistic and achievable in the context of the individual cleanup. Larger watershed issues should be discussed with other resource protection agencies that are part of the process in order to integrate site-specific cleanup into the larger watershed management during the remedy selection process.

8.5 Hyporheic Zone Recovery

The hyporheic zone is defined as a subsurface volume of sediment and porous space adjacent to a stream, river, or lake through which surface water readily exchanges with groundwater. Although the hyporheic zone physically is defined by the hydrology of a body of water and its surrounding environment, it strongly influences the ecosystem of the water body, biogeochemical cycling, and water temperatures. A functioning and intact hyporheic zone provides the biological and geochemical environment for success in many monitored natural recovery remedies that do not involve persistent bioaccumulative organic compounds. For additional information regarding the hyporheic zone and surface water interactions in groundwater/surface water transition zones in ecological risk assessments, see *Evaluating Ground-Water/Surface-Water Transition Zones in Ecological Risk Assessments* (USEPA 2008b).

A hyporheic zone that no longer functions due to sediment contamination can impair or even prevent this zone from geochemically processing waste and providing habitat for aquatic insects, vegetation, and spawning beds for fish and other critical species. Sediment cleanup can act as a catalyst to bring parties together in order to consider larger watershed issues that may need to be addressed. A collaborative model for watershed management issues as well as sediment cleanup is a means to bring these issues forward.

Planning for Hyporheic Zone Recovery

Restoring this zone, either passively or through enhancement during remedy selection, benefits the sustainability of the watershed. Discussion with stakeholders and regulatory resource management agencies to address recovery of this zone should occur throughout the remedy selection and implementation process. Improving habitat, fisheries, and water quality, all of which are functions attributed to this zone, is consistent with existing water resources statutes that may apply, are referenced as a relevant regulation, or are listed as a remedial action objective of the cleanup.

Understanding the status of the hyporheic zone and whether it can be restored to functionality as a result of the sediment cleanup should be a component of any remedial technology selection. Long-term natural recovery remedies must monitor this zone if assessment of pore water and the BAZ are required. Monitoring this zone is usually required to determine whether the sediments can recover to a degree that meets the requirements of the sediment cleanup objectives. If this zone is not defined, then it is difficult to develop monitoring plans to determine whether restoration and a sustainable ecosystem are possible.

The hyporheic zone in a watershed that has not been affected functions to biologically and geochemically treat compounds that would otherwise degrade the quality of the surface water in the watershed's rivers, lakes, and streams. The biological and geochemical status of this zone is important for MNR remedies involving contaminated groundwater discharge to surface water. This is also true for organic chemicals bound to sediment that can be metabolized by bacteria if it degrades a healthy and functioning geochemical and biological environment. An MNR remedy that does not define how this zone is functioning or fails to characterize how it will *recover through monitoring does not provide a foundation for a sustainable resource and could be jeopardizing remedy success.*

Full restoration of this zone may not always be possible, and it may also not always be a significant contributor in terms of watershed health at a site. Incremental improvements that are part of the remedy design can help with even local watershed improvements and thus merit discussion with stakeholders.

8.6 Great Lakes and Regional Watersheds Examples

The Great Lakes watershed offers an example of the regional issues and approaches often relevant to stakeholders for contaminated sites. The Great Lakes regional population dynamics are summarized as follows:

- 25% of U.S. cities with over 100,000 residents live within 100 miles (160 km) of a Great Lakes port.
- 29% of the U.S. population resides in the region.
- 30% of U.S. personal income is distributed in the eight Great Lakes states.
- 31% of the U.S. population over 65 resides in the eight Great Lakes states.

These figures pertain to the U.S. side of the border, but they are comparable for the Canadian portion of the region as well.

Groundwater in the Great Lakes watershed provides the base flow for rivers, lakes, and streams and is the origin of most surface water in Lakes Michigan, Superior, and Huron and, to a lesser degree, Erie and Ontario. This means the vast majority of water in the upper Great Lakes watershed must pass through sediment prior to becoming surface water in the Great Lakes. In Lake Michigan alone, 78% of the water interacts with sediment prior to becoming surface water. Long-term, low concentration, leaching of bioaccumulative compounds from sediments in tributaries affect Lake Michigan. These compounds may circulate in the lake for a century before moving into Lake Huron, remain there for a significant period of time, and then pass on to Lakes Erie and Ontario (USEPA 2012b)

Bioaccumulative substances can have extremely low solubility and are stable compounds known to persist for long periods of time. Continuous interaction with water can leach these substances at their limits of solubility into bodies of water that sustain the Great Lakes or, on a national level, estuaries and oceanic coastal environments where commercial and recreational fisheries and critical ecosystems are located. These substances can exist in or below the BAZ and pose a long-term risk to the watershed while not necessarily demonstrating a risk on a site-specific area. This concern is most critical where groundwater and surface water interact continuously or there is a tidal ebb and flow that continually flushes the sediments in the tidal basins.

In any watershed, continuous groundwater and surface water interaction may cause mobilization of the bioaccumulative compound at the limits of solubility in the dissolved-phase into surface water.

These phenomena may not be significant to local watersheds since low dissolved endocrine disruptor levels are not generally considered to be biologically available. However, the long-term leaching to a body of water such as a Great Lake with a long residence time is likely transferring the chemical to a regional watershed where it may reside for hundreds of years.

Other contaminant transport processes may be site-specific such as spring action and erosion of deeper sediments that mobilize colloidal and particulate matter saturated with these compounds. These long-term contaminant processes take on a much greater significance in the Great Lakes watershed where the rate of flushing of the system is approximately 191 years for Lake Superior and 99 years for Lake Michigan. Cyclical fluctuations in the Great Lakes, often many feet, do not allow for long periods of sediment accumulation to bury the affected sediment below the BAZ. Shallow mud flats can extend for significant distances. Other fine-grained deposits may reside for several years off shore before being redistributed once again by waves as the lake fluctuates in level. Large amounts of sediment and any associated chemicals may be redistributed with each cyclical event.

Based on these watershed dynamics, the vast majority of water in the upper Great Lakes watershed must pass through sediment prior to becoming Great Lakes surface water. The long-term fate of very low solubility bioaccumulative substances discharged to a Great Lake is a concern to stakeholders, because the residence time for those compounds can be hundreds of years to flush through all five lakes. The long-term fate and transport of bioaccumulative substances and endocrine disruptors in systems having continuous flushing with groundwater or tidal influences requires careful evaluation when recommending that significant quantities of these compounds be allowed to remain in the watershed for an MNR or EMNR remedy.

Evaluating all sites from a regional or larger watershed management viewpoint could be part of the decision process because the cumulative impact of multiple sites in a watershed can seriously impair the regional aquatic ecosystem as well as human health, especially with respect to bioaccumulative and endocrine disruptor compounds. Sediments, of course, are not the only sources of bioaccumulatives deposition into the Great Lakes system since aerial deposition from rain and particulates is also of concern. The fish consumption advisories for the entire Great Lakes region are, in part, due to the cumulative impact of multiple sources in the watershed. Ongoing work at the various Great Lakes Areas of Concern will go a long way towards ultimately lifting those advisories.

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APPENDIX A. CASE STUDIES

The purpose of the case study summaries presented in this chapter is to provide an overview of the steps involved with remediating contaminated sediments. Case studies presented in this appendix typically include the following:

- contact information
- brief summary of site characteristics and the remedy employed
- site description including environment, chemicals of concern, primary sources, site history, and a summary of the CSM
- remedial objectives
- remedial approach
- monitoring approach
- references

Table A-1 presents a list of the case study descriptions presented in this appendix, including a summary of the general categories of remedial components (removal, capping, MNR/EMNR, or a combination of these) included at each site. Table A-2 presents a list of the various chemicals of concern associated with each case study.

Each case study description can be accessed by clicking on the site name in Table A-1 or Table A-2.

Table A-1. Remedy components

Case Study Site	Date	EPA Region	Remedy Description	Removal	Capping	MNR or EMNR
Aberdeen Proving Ground, MD	2009	3	Reactive mat with mixture of peat and compost bioaugmented with dechlorinating microbes		X	
Anacostia River, Washington, D.C.	2004 2007	3	Carbon RCM, bulk apatite, AquaBlok		X	
Barge Canal, SC	1998	4	Dredging and capping	X	X	
Bellingham Bay, WA.		10	Removal, cap, MNR	X	X	X
Bremerton Naval Complex (OU B), WA		10	Removal, isolation cap, thin cap, MNR	X	X	X

Table A-1. Remedy components (continued)

Case Study Site	Date	EPA Region	Remedy Description	Removal	Capping	MNR or EMNR
Brookhaven, Peconic River, NY	2005	2	Drying pad dewatering; wet cells for decanting; contaminated sediments landfilled	X		x
Callahan Mining, ME	2009	1	Removal and cap	X	X	
Columbia Slough, OR		10	Source control, hot-spot removal (dredging), and MNR	X		X
Commencement Bay, WA	1989 2000	10	MNR, and dredging and capping	X	X	X
Continental Steel, IN	2007	5	Dewatered; drying pads, sand and activated charcoal filtering; landfilled; CAMU; PCB and VOC disposed off site at permitted facility	X		X
Detroit River. Black Lagoon, MI	2005	5	GLLA demo; mechanical dredging and disposal	X	X	
DuPont Gill Creek (SH1), NY	1992	3	Dewatered with sand bags & cofferdams; stabilized with fly ash & kiln dust then disposed of in TSCA/RCRA landfills. 230 yd^3 incinerated	X		X
DuPont Newport, DE	1993	3	Removal	X		
Eagle (East) Harbor, Wycoff, WA	1997	10	Dewatered; hotspot CDF disposal; large material landfilled; clean sediment backfill, capping	X	X	X
East Doane Lake, OR	1998		Removal, on-site disposal	X		

Table A-1. Remedy components (continued)

Case Study Site	Date	EPA Region	Remedy Description	Removal	Capping	MNR or EMNR
Formosa Plastics, TX	1992	6	Cofferdam dewatering; partially dewatered sediments mixed with cement & barged to offload & disposed at RCRA-compliant landfill	X		
Fox River & Green Bay, WI	1998	5	Removal hydraulic cutterhead with swinging ladder	X		
Fox River & Green Bay (OU 1,OU 2), WI	2002	5	Removal auger, MNR	X		
Fox River & Green Bay(OU 2, OU 3, OU 4), WI	2009	5	Removal swinging ladder and capping	X	X	
Fox River & Green Bay (OU 2, OU 3, OU 4), WI	2013	5	Proposed removal and off-site disposal	X		
Fox River (Lower) Green Bay (SH2), WI	2009	5	MNR 20 miles of river			X
Galaxy/Spectron (SH3), Elkton, MD	1999	3	Removal, GCL cap, GWTS	X	X	
GM Massena St. Lawrence River, NY	1995	2	Removal and backfilled	X		
Grand Calumet River (West Branch), Hammond, IN	2003	5	Removal disposal	X		
Grasse River, Massena, NY	2001	2	Pilot study of various capping materials, and evaluation of scouring caused by ice jam		X	
Grasse River (Hot Spot Removal), NY	1995	2	Removal, hydraulic dredging, vacuum dredging and on-site disposal	X		

Table A-1. Remedy components (continued)

Case Study Site	Date	EPA Region	Remedy Description	Removal	Capping	MNR or EMNR
Grasse River (Pilot), NY	2005	2	Hydraulic cutterhead and on-site disposal	X		
Grubers Grove Bay, WI	2001	5	Hydraulic dredging, Geotubes for dewatering	X		
Hackensack River, NJ	2006	2	Removal, cap, MNR	X	X	X
Hooker,102nd St., Niagara Falls (SH4), NY	1990	2	Dredging, cap, and MNR	X	X	X
Housatonic River, MA	2002	1	Isolation cap installed on area not dredged; dredged areas backfilled and seeded/replanted.	X	X	
Hudson River Poughkeepsie (EPRI), NY	2009	2	Organoclay/sand marine mattress and organoclay RCM	X	X	X
Hudson River (Hot Spots), NY	2009	1	Excavation and off-site disposal	X	X	
Ketchikan Pulp, AK	2001	10	Removal, cap, MNR	X	X	X
Kokomo and Wildcat Creeks, IN	2007	5	Creek dewatered and sediment removed; treated with AC prior to disposal	X		
Koppers Co., Inc., Former Barge Canal, Charleston, SC	1998	4	Removal, cap, MNR	X	X	X
Koppers Newport, DE	2005	3	Source control, excavation and capping	X		
Lavaca Bay Area, TX	1999	6	Hydraulic cutterhead dredge	X		X
Lavaca Bay, Point Comfort, TX	2001	6	Removal, MNR	X		X
Love Canal, NY	1987	2	Excavation	X		

Table A-1. Remedy components (continued)

Case Study Site	Date	EPA Region	Remedy Description	Removal	Capping	MNR or EMNR
Lower Duwamish, Marathon Battery (OU 1), NY	1986	2	Removal	X		
Manistique River & Harbor, MI	1993	5	Hydraulic dredging, cap, MNR	X	X	X
Messer Street, Laconia (SH5), NH	2001	1	Removal	X		
McCormick & Baxter Site, Willamette River (SH6), Portland, OR	1996	10	Cap	X	X	
McCormick & Baxter (SH7), Stockton, CA	1999	9	Cap		X	
Metal Bank, Delaware River, PA	1997	3	Mechanical dredging, cap	X	X	
Milltown Reservoir, Missoula County, MT	2004	8	Removal, MNR	X		X
Money Point, VA	2009	3	Removal, thermal treatment of removed sediments	X		X
Natural Gas Compressor Station, MS	1997	4	Removal and stabilization	X		
New Bedford (Hot Spots) (SH8), MA	1995	1	Hydraulic cutterhead dredge, slurry pipe to off-site TSCA disposal	X		
New Bedford (SH9), MA	2004	1	Two hydraulic cutterheads, sediments dewatered and disposed in TSCA facility	X		
McAllister Point, Naval Station, Landfill (OU 4), RI	1996	1	Removal, removed rock decontaminated	X	X	

Table A-1. Remedy components (continued)

Case Study Site	Date	EPA Region	Remedy Description	Removal	Capping	MNR or EMNR
Ottawa River, Canada	1998		Hydraulic dredging; GLLA AOC demo, including AquaBlok	X		
Ottawa River, Toledo, OH		5	Hydraulic dredging and off-site disposal	X		
Pegan Cove, MA	2010	1	Removal hydraulic cutterhead and slurry pumped into Geotextile bags	X		
Penobscot River (Dunnett's Cove), Me	2010	1	Cap designed to trap NAPL		X	
Pettit Creek Flume, NY	1994	2	Removal and disposal	X		
Pine Street Canal, VT	1998	1	Sand cap and cap amended with organophilic clay		X	
Pioneer Lake, OH	1997	5	Hydraulic cutterhead dredging and disposal in landfill or hazardous waste landfill depending on concentrations	X		
Port of Portland, OR	2009	10	Bulk organoclay		X	
Port of Tacoma Piers 24 and 25, WA	2005	10	Debris removal, excavation, and capping	X	X	
Queensbury NMPC (OU 1)	1996	NA	Removal, stabilized prior to disposal	X		
Randall Reef, Ontario, Canada	2010	NA	Dredging and on-site disposal	X		
Reynolds, NY	1996	2	Mechanical dredging stabilized or shipped to hazardous waste landfill. Concentration dependent	X	X	
Sapp Battery Salvage Yard, Jackson County, FL	1986	4	removal, wetland	X		

Table A-1. Remedy components (continued)

Case Study Site	Date	EPA Region	Remedy Description	Removal	Capping	MNR or EMNR
Sheboygan River & Harbor, WI	2000	5	Removal, MNR	X		X
Shiawassee River, MI	2001	5	Removal, MNR	X		X
Stryker Bay (SLRIDT Superfund), Duluth, Mn	2004	5	Dredging, AC RCM	X	X	
Starkweather Creek, WI	1993	5	Removal	X		
Sullivan's Ledge, MA	2001	1	Backhoes and long reach excavators, stabilized w/ lime kiln dust	X	X	
Torch Lake Superfund Site, MI	1994	5	Capping, MNR		X	X
Town Branch, KY	2000	4	Removal, DNAPL recovery	X		
Ten Mile / Lange Revere Canal, MI	2003	5	Removal, stabilization of sediment before disposal	X		
Tennessee Product, TN	1998	4	Removal, NAPL site capped with AquaBlok	X	X	
Terry Creek, GA	2000	4	Cable arm clamshell	X		
Twelve Mile Creek / Lake Hartwell	1994	4	MNR			X
Velsicol, MI	2007	5	Proposed removal, cap	X	X	
Vineland Chemical, NJ	1989	2	Excavation, MNR	X		X
Waukegan Harbor (Outboard Marine), IL	1989	5	Removal, thermal desorption of removed sediments	X		

Table A-1. Remedy components (continued)

Case Study Site	Date	EPA Region	Remedy Description	Removal	Capping	MNR or EMNR
West Branch Grand Calumet River (WBGCR) (Reaches 3, 4-5), Hammond, IN	2010, 2011	5	AC RCM	X	X	
White Lake, MI	2003	5	Removal and disposal, dried and off-site disposal	X		
Wyckoff/Eagle Harbor (OU 1 & OU 3), WA	1992	10	Cap, MNR, and institutional controls		X	X
Zidell - Willamette River, OR	2005	10	Dredging, cap, and MNR	X	X	X

Table A-2. Chemicals of concern

	Contaminants of Concern (compounds other than those listed were not considered)				
Case Study Site	PCB	PAHs	Metals	Dioxin	Other Pollutants
Aberdeen Proving Ground, MD 2009					Chlorinated aliphatics
Anacostia River, Washington, D.C. 2004, 2007		X	X		
Barge Canal, SC 1998		X	As, Pb, Cr, Cu	X	PCP
Bellingham Bay, WA.		4-MP and phenol	Hg		
Bremerton Naval Complex (OU B), WA	X		Hg		
Brookhaven, Peconic River, NY 2005	X		Hg, Ag, Cu		
Callahan Mining, ME 2009	X		As, Cd, Cu, Pb, Zn		
Columbia Slough, OR	X	X	Pb		Pesticides
Commencement Bay, WA 1989, 2000	X	X	As, Cd, Cu, Hg, Pb, Zn		VOCs and phthalates
Continental Steel, IN 2007					
Detroit River, Black Lagoon, MI 2005	X		Hg, Pb, Zn		Oil and grease
DuPont Gill Creek (SH1), NY 1992	X		Hg		VOCs

	Contaminants of Concern (compounds other than those listed were not considered)				
Case Study Site	PCB	PAHs	Metals	Dioxin	Other Pollutants
DuPont Newport (SH1), DE 1993			Cd, Pb, and Zn (variable depending on OU - see case study)		
Eagle (East) Harbor, Wycoff, WA 1997		X	Hg, Pb, Cu, Zn		Creosote, PCP
East Doane Lake, OR 1998			Pb	X	
Formosa Plastics, TX 1992					Ethylene dichloride
Fox River & Green Bay, WI 1998	X		Hg		
Fox River & Green Bay (OU 1, OU 2), WI 2002	X		Hg		
Fox River & Green Bay (OU 2, OU 3, OU 4), WI 2009	X	X	Hg, Pb, As	X	Furan, DDT
Fox River & Green Bay (OU 2, OU 3, OU 4), WI 2013	X		Hg, Pb, As	X	Furan, DDT
Fox River (Lower) Green Bay (SH2), WI 2009	X	X	Hg, Pb, As	X	Furan, DDT
Galaxy/Spectron (SH3), Elkton, MD 1999					DNAPL, VOCs
GM Massena St. Lawrence River (SH3), NY 1995	X				
Grand Calumet River (West Branch), Hammond, IN 2004	X	X	X		Cyanide
Grasse River, Massena, NY 2001	X		X		
Grasse River (Hotspot Removal), NY 1995	X				
Grasse River (Pilot), NY 2005	X				
Grubers Grove Bay, WI 2001			Hg, Cu, Pb, Zn		Methyl mercury
Hackensack River, NJ			Cr		
Hooker, Niagara Falls, 102nd St.(SH4), NY 1990		X			
Housatonic River, MA					
Hudson River Poughkeepsie (EPRI), NY 2009		X			Coal tar NAPL
Hudson River (Hot Spots), NY 2009	X				
Ketchikan Pulp, AK 2001	X		Pb, As		NH4, H2S, petroleum
Kokomo and Wildcat Creeks, IN 2007	X	X	Pb, As, Be		VOCs

	Contaminants of Concern (compounds other than those listed were not considered)				
Case Study Site	**PCB**	**PAHs**	**Metals**	**Dioxin**	**Other Pollutants**
Koppers Co., Inc., Former Barge Canal, Charleston, SC 1998		X	As, Pb, Cr, Cu	X	
Koppers Newport, DE 2005		X			NAPL
Lavaca Bay Area, TX 1999		X	Hg		
Lavaca Bay, Point Comfort, TX 2001		X	Hg		Methylmercury
Love Canal, NY 1987		X	X	X	VOCs and pesticides
Lower Duwamish, Marathon Battery (OU 1), NY 1986			Cd, Ni, Co		TCE
Manistique River & Harbor, MI 1993	X				
Messer Street (SH5), Laconia, NH 2001					
McCormick & Baxter Site, Willamette River(SH6), Portland, OR 1996			X	X	
McCormick (SH7) & Baxter, Stockton, CA 1999		X		X	
Metal Bank, Delaware River, PA 1997	X	X		X	
Milltown Reservoir, Missoula County, MT 2004			As, Cu, Cd, Pb, Zn	X	Creosote NAPL
Money Point, VA 2009		X	As, Cr, Cu, Pb, Zn		
Natural Gas Compressor Station, MS 1997	X				
New Bedford (Hot Spots) (SH8), MA 1995	X		X		
New Bedford (SH9), MA 2004	X		X		
New Castle County, DE 1997		X			NAPL
McAllister Point (Naval Station) Landfill (OU 4), RI 1996					
Ottawa River, Canada 1998	X	X			
Ottawa River, Toledo, OH	X	X			
Pegan Cove, MA 2010		X			VOCs, BTEX, coal tar
Penobscot River (Dunnett's Cove), MN 2010		X			coal tar NAPL
Pettit Creek, NY					DNAPL VOCs and SVOCs
Pine Street Canal, VT		X	X		NAPL, VOCs
Pioneer Lake, OH		X			

	Contaminants of Concern (compounds other than those listed were not considered)				
Case Study Site	PCB	PAHs	Metals	Dioxin	Other Pollutants
Port of Portland, OR 2009			Pb	X	
Port of Tacoma Piers 24 and 25, WA 2005	X	X	Cu, Hg, Zn		Phenanthrene, dibenz(a,h) anthracene, hexa-chlorobutadine (HCBD)
Queensbury NMPC (OU 1)	X				
Randall Reef, Ontario, Canada 2010		X	X		
Reynolds, NY 1996	X	X			Dibenzofurans
Sapp Battery Salvage Yard, Jackson County, FL 1986			Pb		
Sheboygan River & Harbor, WI	X				
Shiawassee River, MI 2001	X				
Stryker Bay (SLRIDT Super-fund), Duluth, MN 2004					
Starkweather Creek, WI 1993			Mg, Cr, Pb		Oil and grease
Sullivan's Ledge, MA 2001	X	X			
Torch Lake Superfund Site, MI 1994	X	X	X		Coal tar, nitrate, ammonia, waste from explosive man-ufacturing
Town Branch, KY 2000	X				
Ten Mile / Lange Revere Canal, MI 2003	X				VOCs, SVOCs
Tennessee Product, TN 1998		X			
Terry Creek, GA 2000					Toxaphene
Twelve Mile Creek / Lake Hartwell, 1994	X				
Velsicol, MI 2007	X		X		PPB, DDT, pesticides, brom-inated compounds, rare earth metals and radioactive con-taminants
Vineland Chemical, NJ 1989			As		
Waukegan Harbor, (Outboard Marine), IL 1989	X				
West Branch Grand Calumet River (WBGCR) (Reaches 3, 4-5), Hammond, IN 2010, 2001	X	X	X		Pesticides
White Lake, MI 2003			Cr, As, Hg		Tannery waste
Wyckoff/Eagle Harbor (OU 1 & OU 3), WA 1992		X	X		Creosote and penta-chlorophenol
Zidell - Willamette River, OR 2005	X	X	X		TBT

A.1 Aberdeen Proving Ground, MD

A.1.1 Contacts

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A.1.2 Summary

Environment:	Tidal wetland
Scale:	Pilot
Contaminants of Concern:	Chloroform, carbon tetrachloride, tetrachloroethene, 1,1,2,2-tetrachloroethane, hexachloroethane, pentachloroethane
Final Remedy:	Active cap (reactive mat with mixture of peat and compost bioaugmented with dechlorinating microbes)

A.1.3 Site Description

The Aberdeen Proving Ground (APG) is a 72,500 acre Army installation located off Route 40 in Edgewood (Harford County), on the western shore of the upper Chesapeake Bay. The Bush River divides APG into two distinct areas: the Edgewood Area to the west and the Aberdeen Area to the east. Beginning in 1917, the Edgewood Area of the site was used to conduct chemical research programs, to manufacture chemical agents, and to test, store, and dispose of toxic materials. Contaminants may have been introduced to the surficial aquifer at the site as multiple nonpoint source releases of solvents during site operations, resulting in a plume of contaminated groundwater that flows toward the tidal wetland. The site was formally added to the National Priorities List February 21, 1990.

Seep areas have been identified in the tidal wetland, where natural attenuation of chlorinated solvents by anaerobic biodegradation is hindered by the increase in vertical seepage flux and the resulting decrease in residence time in the wetland sediments. The area of concern is located in a tidal wetland along West Branch Canal Creek, where localized areas of preferential discharge (seeps) transport contaminated groundwater. Groundwater contaminated with chlorinated VOCs discharges from a 30–50 ft aquifer to the wetlands and tidal creek.

CSM summary: The CSM for the site noted that the major transport mechanism for VOCs was preferential seepage of contaminated groundwater from the aquifer to West Branch Canal Creek. The pilot study divided the seeps into two categories:

- Focused seeps: locations with the highest concentrations of chlorinated parent compounds, relatively low concentrations of chlorinated degradation products, and insignificant concentrations of methane in shallow pore-water samples (primarily occurring along the creek edge or forming a dendritic-like pattern between the wetland and creek channel).
- Diffuse Seeps: locations characterized by relatively high concentrations of chlorinated degradation products (or a mixture of compounds and their degradation products) and detectable methane concentrations in shallow pore-water samples primarily occurring along the wetland boundary.

The seep used during the pilot study (seep 3-4W) was characterized as a focused seep.

A.1.4 Remedial Objectives

Remediation risks included adverse effects to wetland water quality from nutrients or metals mobilization. RAOs/project objectives included:

- achieve 90% removal of VOCs in mat
- establish and maintain conditions conducive to WBC-2 survival (redox, pH)
- achieve hydraulic compatibility
- achieve geotechnical stability (settlement 0.4–1 ft)
- cause no adverse effects to wetland water quality from nutrients or metals mobilization

A.1.5 Remedial Approach

Final selected remedy: Active cap (reactive mat with mixture of peat and compost bioaugmented with dechlorinating microbes).

A pilot study was conducted using a permeable reactive mat placed at the groundwater/surface water interface, which encouraged anaerobic biodegradation. The mat consisted of a mixture of peat and compost bioaugmented with dechlorinating microbes. Performing a pilot study before launching a full-scale remedy allowed necessary modifications to be made at a much lower cost.

The top 1 ft of wetland sediment was removed with a vacuum truck. Mixtures for the reactive mat were put down (22 inches total). The mat initially extended above the wetland surface to allow for settling. The reactive mat was designed to optimize chlorinated volatile organic compound degradation efficiency without altering geotechnical and hydraulic characteristics, or creating undesirable water quality in the surrounding wetland area.

A.1.6 Monitoring

Monitoring by the USGS over a one-year period (October 2004 to October 2005) showed consistent mass removal in the mat, even during the cold winter months. The success of the remedy in meeting remedial goals was shown through performance monitoring that involved several aspects of the remedy. Groundwater and surface water were sampled to monitor contaminant concentrations. The reactive mat matrix was sampled to monitor microbial activity. Because a permeable reactive mat was used, groundwater level and hydraulic head surrounding the mat were monitored to ensure the placement of the mat did not create new seeps.

RAOs/project objectives achieved? The pilot study was deemed a success based on data gathered through performance monitoring. Total chloromethanes decreased as the plume moved from the base of the mat upward to the mat surfaces. Mass removal was estimated at 95–99.99%. Chlorinated ethenes and ethanes were similarly reduced.

A.1.7 References

USGS. 2011. MD-DE-DC Water Science Center: Enhanced Bioremediation of Chlorinated Solvents in Wetland Seep Areas, Aberdeen Proving Ground: WBC-2 Dechlorinating Culture and Reactive Mat Pilot Test. http://md.water.usgs.gov/posters/biomat/index.html.

Majcher, E.H., Lorah, M.M., Phelan, D.J., and McGinty, A.L., 2009. "Design and performance of enhanced bioremediation pilot test in a tidal wetland see, West Branch Canal Creek, Aberdeen Proving Ground, Maryland". U.S. Geological Survey Scientific Investigations Report 2009-5112, 70pp.

A.2 Anacostia River, Washington, D.C.

A.2.1 Contacts

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A.2.2 Summary

Environment:	River
Scale:	Pilot (field scale)
Contaminants of Concern:	PAHs, metals
Final Remedy:	Amended capping

A.2.3 Site Description

A demonstration of amended capping was conducted at the Anacostia River in Washington D.C. as described by Reible et al. (2006).

A.2.4 Remedial Approach

Final selected remedy: Amended capping

Four caps were placed in the spring of 2004 to assess the potential effectiveness of capping on a field scale. The four capping materials used were AquaBlok, coke in a Reactive Core Mat, apatite, and sand. AquaBlok is a manufactured clay-like material for permeability control. Coke is a by-product of coal manufacturing and is an inexpensive, moderately strong sorbent of organic compounds. The use of coke in the demonstration primarily served to evaluate placement of AC or other low-density material in a thin mat. Apatite has been proposed for the sequestration of heavy metals.

All bulk caps were successfully placed using a clamshell bucket. The caps were constructed with a nominal thickness of six inches overlain by a six-inch sand layer. The coke was placed in a reactive core mat with a thickness of less than one inch overlain by a six-inch sand layer.

A.2.5 Monitoring

The AquaBlok cap effectively eliminated groundwater upwelling in the area capped and to divert groundwater towards the center of the river (Reible et al. 2006). The AquaBlok cap was monitored with an inclinometer, which provided unique information on vertical cap movements. Because of the interaction of tides with the hydrostatics of the groundwater, the AquaBlok cap uplifted 0.1-0.5 mm every tidal cycle (up at low tide and down at high tide). In addition, continued gas formation in the river sediments led to an accumulation of gas beneath the low-permeability layer. After approximately 1½ months, the lower end of the AquaBlok lifted approximately 0.75 m to release gas, and this behavior continued approximately every six weeks throughout the summer. This behavior was not noted in the summer of 2005, although it is unclear if that was due to failures of the inclinometer, a cessation of significant gas ebullition due to the consumption of labile organic matter, or normal migration through a compromised AquaBlok layer.

The coke layer was also monitored extensively using bulk-solid monitoring, bioaccumulation monitoring, and passive sampling for PAHs in the interstitial space of the sediment and cap layers. Bulk solid monitoring showed the accumulation of new sediment on the top of the cap due to nearby stormwater drains and, potentially, surficial sediment migration (Reible et al. 2006). This result demonstrated the potential for recontamination due to stormwater inputs and confirmed methods for evaluating its influence. Bioaccumulation monitoring in caged organisms and passive interstitial pore-water sampling (using polydimethylsiloxane partitioning samplers) showed a good correlation between pore-water concentrations and bioaccumulation of PAHs and also indicated the performance of the cap (Lampert, Lu, and Reible 2013). The coke layer was not designed to significantly retard contaminant migration through the cap but instead to demonstrate the ability to place light sorbents in a reactive core mat (this was the first application of a reactive core mat for sediment remediation).

As expected, the monitoring results three to five years after placement showed that the caps were at steady state relative to organic contaminant migration through the cap. Even at steady state with upwelling velocities of the order of 1 cm/day, the concentrations in the near-surface biologically active zone were 70-80% lower than concentrations prior to capping.

A.2.6 References

Reible, D., Lampert, D., Constant, D., Mutch Jr, R. D., & Zhu, Y. 2006. Active capping demonstration in the Anacostia River, Washington, DC. *Remediation Journal* 17(1), 39-53.

Lampert, D. J. X. Lu, D. D. Reible. 2013. Long-term PAH Monitoring Results from the Anacostia River Active Capping Demonstration Using Polydimethylsiloxane (PDMS) Fibers. *Environmental Science: Processes & Impacts*.

A.3 Bellingham Bay, Whatcom Waterway, Bellingham, WA

A.3.1 Contacts

Regulatory Contact: WDOE

A.3.2 Summary

Environment:	Marine Embayment
Scale:	Full
Contaminants of Concern:	Mercury, 4-methylphenol, phenol. Mercury is the only bioaccumulative COC.
Source Control Achieved Prior to Remedy Selection?	Yes
Final Remedy:	MNR (110 acres), capping and dredging (90 acres)
Expected Recovery Time:	30 years
MNR viewed as a success?	Yes

A.3.3 Site Description

The Whatcom waterway site runs along the downtown Bellingham waterfront and covers more than 200 acres in Bellingham Bay, as well as a former industrial waste treatment lagoon. The primary sources of contamination for this site are past direct discharges and releases from a former Georgia-Pacific chlor-alkali plant. Mercury was discharged in wastewater directly into Bellingham Bay from 1965-1971. Treatment methods reduced these mercury levels until 1979, when an aerated stabilization basin was installed which eliminated effluent released into the bay. The plant was shut down in 1999.

In 2000, an RI/FS was completed for the Star Rock sediment disposal area. Sediments dredged from the Whatcom waterway and adjacent areas deposited there during the 1960s dredging operations served as an internal source of mercury to the site. Cleanup and habitat restoration activities were carried out in 2000/2001. In 2007, a Consent Decree, including a cleanup action plan, was signed for the Whatcom Waterway site.

CSM summary: The primary natural recovery processes at Whatcom Waterway is physical isolation. Lines of evidences collected to demonstrate this include sediment traps to determine sedimentation rates, bathymetry data to corroborate sedimentation rates, sediment coring to demonstrate historical mercury recovery and sediment bioassays to determine acute and chronic risks to benthos. The results of the sediment bioassays were further corroborated by the biological endpoint monitoring record which indicated that the environmental exposure at the site had been reduced to below risk targets.

A.3.4 Remedial Objectives

Concerns for this case study include both ecological and human health risks associated with mercury. The objective of the sediment cleanup is to achieve compliance with cleanup standards in surface sediments of the bioactive zone (40 mg/kg, WDOE sediment quality standard). These are standards are defined in the 2007 Cleanup Action Plan for the site.

A.3.5 Remedial Approach

Final selected remedy: MNR (110 acres), capping and dredging (90 acres)

The final remedy (Alternative 6) targets the highest contaminated sediments in areas that are likely to be disturbed and can be removed without excessive short-term risk. This remedy consists of dredging the Aerated Stabilization Basin (ASB) and the outer waterway. The inner waterway multipurpose channel was dredged and then capped. Capping followed by MNR was selected for offshore low-energy areas in the bay.

Eight alternatives were considered for the site. Four of these alternatives were determined to be non-implementable. The remaining four alternatives included several combinations of dredging, capping, and MNR for various areas of the bay. The criteria used to evaluate the alternatives follow WDOE's Model Toxics Control Cleanup Act (MTCA) and Sediment Management Standards and include:

- overall protectiveness increases with volume of sediment removed
- performance increases with volume of sediment removed
- long-term effectiveness increases with use of high-preference remediation technologies
- short-term risk management decreases with increased dredging
- implementability

- consideration of public concerns addresses volume of contamination
- restoration time
- probable cost

Alternative 6 was determined to be “permanent to the maximum extent practicable” under the MTCA since it provided the greatest overall benefit of the practicable alternatives.

The primary lines of evidence used to investigate physical isolation included sediment core sampling and radioisotope analysis, bathymetric and sediment traps data, recovery and exponential decay modeling, and analysis of temporal trends in sediment toxicity test results.

A.3.6 Monitoring

Monitoring of physical isolation rates (long-term natural recovery performances) will include bathymetric surveys, sediment cores, and visual inspection of intertidal and shoreline areas. Risk reduction (remedial goal) monitoring will include surface sediment chemistry surveys (years 0, 1, 3, 5, 10, 20, and 30) as well as mercury bioaccumulation monitoring in Dungeness crabs during years 3, 5, and 10.

Expected recovery time: 30 years

Projected monitoring costs: $1 million

RAOs/project objectives achieved? MNR is viewed as a success at this site. Analysis of historical natural recovery shows that MNR has been a successful remedy at Bellingham Bay. Mercury concentrations and toxicity have been reduced in sediments due to natural recovery over time. Models predicted mercury concentrations in surface sediments to be in compliance with cleanup standards by 2005; however, updated information is not available to confirm whether current mercury concentrations validate the model.

A.3.7 References

WDOE Whatcom Waterway. https://fortress.wa.gov/ecy/gsp/Sitepage.aspx?csid=219.

A.4 Bremerton Naval Complex, WA

A.4.1 Contacts

Regulatory Contacts: US Navy, USEPA, WDOE

A.4.2 Summary

Environment:	Marine embayment
Scale:	Full
Contaminants of Concern:	PCBs, mercury
Source Control Achieved Prior to Remedy Selection?	Yes
Final Remedy	MNR (230 acres), dredging, isolation capping, and thin-layer capping (61 acres)
Expected Recovery Time	10-30 years
MNR viewed as a success?	Not yet determined

A.4.3 Site Description

This site is located at the Bremerton Naval Complex (BNC), Operable Unit B. The entire Bremerton Naval Complex site includes 380 acres of upland and 270 acres of sediment in the southwest region of Puget Sound, on the Sinclair Inlet in Bremerton, WA. This case study focuses on the 230 acres of OU B (marine), one of the six areas of interest. This area is primarily subtidal land extending 1,500 ft offshore to depths of approximately 40 ft below mean lower low water.

The BNC has been in operation since the 1890s. Operations have included shipbuilding and vehicle maintenance, berthing for naval vessels, commercial activities, and housing. The BNC includes both the Puget Sound Naval Shipyard (PSNS) and the Naval Station Bremerton (NSB). The PSNS provides overhaul, maintenance, conversion, refueling, defueling, and repair services to the naval fleet. NSB serves as a deep draft home-port for aircraft carriers and supply ships.

The primary sources of contamination at this site are past direct discharges and releases, including from miscellaneous waste material used as fill during expansion of the Naval Complex as well as ongoing minor releases from upland soils via stormwater discharge. Hazardous materials generated during fleet support activities that are believed to be contained in the fill substrates below the site include metal plating, metal filings, electrical transformers (containing PCBs), batteries, paint and paint chips (containing heavy metals), acids, and other caustic substances.

CSM summary: The primary natural recovery process at the Bremerton site is physical isolation. Lines of evidence collected to support continuing sedimentation (0.5 - 0.75 cm/yr) and concurrent absence of erosional areas include:

- Bathymetry: current and historical data collected to determine sedimentation rates
- Sediment profile imaging: sediment mapping to characterize substrate and recently deposited layers

A.4.4 Remedial Objectives

The main risk concerning this case study is human health, primarily from PCBs in fish tissue. Currently, subsistence tribal fishermen consume seafood from the BNC site as well as nearby locations in Sinclair Inlet. It is possible that they could also consume seafood from other areas of the site in the future if these areas are opened up. Mercury was found to be a risk driver for human health after the completion of the RI, therefore it was included in the ROD; however, a cleanup level was not identified.

RAOs/project objectives for this site include the following:

- Reduce the concentration of polychlorinated biphenyls (PCBs) in sediments to below the minimum cleanup level of 3 mg/kg organic carbon (OC) in the biologically active zone (0 to 10 cm depth) within OU B marine, as a measure expected to reduce PCB concentrations in fish tissue.
- Control shoreline erosion of contaminated fill material at Site 1.
- Selectively remove sediment with high concentrations of mercury collocated with PCBs.

Site-specific cleanup levels for sediments and remedial goals for fish include:

- remedial action level for total PCBs in sediment of 6 mg/kg organic carbon (OC) for the biologically active zone (0-10 cm) throughout OU B (marine)
- long-term cleanup goal for total PCBs in Sinclair Inlet sediments equivalent to the reference area concentration of 1.2 mg/kg OC
- PCB remedial goal for fish tissue of 0.023 mg/kg wet weight

A.4.5 Remedial Approach

Final selected remedy: MNR (230 acres), dredging, isolation capping, and thin-layer capping (61 acres)

The remedy included dredging, thin-layer capping, MNR, and shoreline stabilization to reduce erosion of contaminated sediments. Dredging was selected for sediments with PCB levels of 12 mg/kg OC (approximately 200,000 yd^3 of sediment). After dredging, the area-weighted average PCB concentration in sediments was expected to be reduced from 7.8 mg/kg OC to 4.1 mg/kg OC. After, MNR was expected to further reduce risks through natural deposition.

Thin-layer capping was selected for areas with PCB concentrations exceeding 6 mg/kg OC (approximately 16 acres adjacent to OU A). Another 13 acres in OU B were treated with isolation capping.

After implementing dredging and capping, MNR was expected to reduce the area-weighted PCB concentration in OU B sediments to below 3 mg/kg OC within 10 years (by 2014). The reference area goal (1.2 mg/kg OC) is expected to be reached within 30 years (2034).

A.4.6 Monitoring

Monitoring activities verified that remedial goals had been reached, confirmed the predicted natural recovery of sediments, and evaluated the remediation success in reducing COC concentrations in fish tissue. Long-term monitoring started with a baseline evaluation in 2003 and addition assessments were to be conducted in 2005, 2007, 2012, and 2017. Activities detailed in the 2005 Final Marine Monitoring report (URS Group 2006) included:

- Bathymetric surveys: Sediment elevations measured in 2001, 2003, and 2005 track each other within the range of expected intersurvey variability (1-2 ft.).
- Surface sediment sampling: PCB concentrations exceeded the 3 mg/kg OC short-term goal.
- Ongoing natural recovery modeling: Modeling based on the 2005 data predicts that natural recovery will likely not meet the goals set out in the ROD in the expected 10-year time frame.

Expected recovery time: 10-30 years

Projected monitoring costs: $2,500,000

RAOs/project objectives achieved? MNR is viewed as a success at this site. Results on monitoring activities through 2007 indicate that decreasing PCB concentrations are consistent with the cleanup goal target date of 2014.

A.4.7 References

USEPA Puget Sound Naval Shipyard Complex website. http://yosemite.epa.gov/r10/cleanup.nsf/7780249be8f251538825650f0070bd8b/fb496707a24fb2478825654b00793b26!OpenDocument.

USEPA. 2004. USEPA Superfund Explanation of Significant Differences: Bremerton Naval Complex, Operable Unit B. USEPA ID: SCD980310239, OU 01, Charleston, SC. U.S. Environmental Protection Agency, Region 4.

A.5 Brookhaven, NY

A.5.1 Summary

Environment:	Freshwater
Scale:	Full
Contaminants of Concern:	Hg: 39.7 ppm max, Ag: 380 ppm max, Cu: 1490 ppm max, PCB (aroclor-1254): max 1.5 ppm
Final Remedy:	A sediment-drying pad was constructed to dewater sediment prior to disposal. Water was treated at a separate unit before going back into the river. On-site, 60 ft x 60 ft wet cells used to decant the sediments. Contaminated sediment was deposited at a landfill.

A.5.2 Site Description

The Brookhaven National Laboratory (BNL) site is located along the Peconic River in Suffolk County, New York. The site and site remediation are described in the site close-out report (Envirocon 2005). Approximately 14,025 linear feet (2.66 miles) of the Peconic River was contaminated. Water depth at the site was approximately 0–30 ft, the target volume for removal was 1134 tons, and the actual volume removed was 1134 tons.

A.5.3 Remedial Objectives

The remedial objectives for this site included:

- SWAC: Less than 1 ppm Hg for entire BNL property; less than 2 ppm Hg for remediated area
- contaminated sediment thickness of 1 ft

A.5.4 Remedial Approach

Partial dry excavation was achieved with mechanical excavators working from timber crane mats. Excavators were equipped with flat blade buckets. Cleanup achieved remedial objectives by reducing average Hg concentration outside Brookhaven National Laboratory property to 0.092 ppm with all samples less than 2 ppm.

The dredged area that had been a marsh was backfilled with 6–12 inches of clean river sediment for restoration. MNR is in effect to restore the marsh environment. One silt barrier was placed at northern most region to prevent further migration of contaminants.

A.5.5 Monitoring

A long-term monitoring plan is in place to assure the protection of human health and the environment. Very few details are available for resuspension monitoring.

RAOs/project objectives achieved? Based on confirmatory sampling, cleanup levels were met.

A.5.6 References

EPA Superfund Record of Decision: Brookhaven National Laboratory (USDOE). USEPA ID: NY7890008975. Jan 2005. http://www.epa.gov-/superfund/sites/rods/fulltext/r2005020001410.pdf.

Environcon, Inc. Final Closeout Report Peconic River Remediation Phases 1 and 2 Brookhaven National Laboratory. Aug 2005. http://www.bnl.gov/gpg/files/Closeout_reports/PR_Closeout_Report_v1.pdf.

Brookhaven National Laboratory. Final Five-Year Review Report for Brookhaven National Laboratory Superfund Site. July 2006. http://www.epa.gov-/superfund/sites/fiveyear/f0602019.pdf.

A.6 Callahan Mining, ME

A.6.1 Contacts

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A.6.2 Summary

Environment:	Tidal estuary
Scale:	Full
Contaminants of Concern:	Arsenic, PCBs, cadmium, copper, lead, zinc
Source Control Achieved Prior to Remedy Selection?	No
Final Remedy:	Removal and capping
MNR viewed as a success?	Remedy in proposal phase

A.6.3 Site Description

The Callahan Mine site is located approximately 1,000 ft (305 meters) east-southeast of Harborside Village in the town of Brooksville, Hancock County, Maine. Mining operations were conducted adjacent to and beneath Goose Pond. The 150-acre property is located in a coastal, rural setting on the Cape Rosier peninsula. The mine is currently underwater and subject to daily tidal exchange in Goose Pond. Goose Pond is connected to Goose Cove to the north by Goose Falls. Goose cove is on the southern part of Penobscot Bay.

Site contamination is attributed to spillage during transport, storage, and handling of ore and ore concentrate; disposal of tailings, disposal of waste rock; and contaminated wind-blown dust. PCB contamination is attributed to historical transformer leakage. The zinc/copper sulfide deposit in Goose Pond was discovered in 1880 at low tide. Efforts to mine the ore continued until 1964. Open pit mining activities began in 1968. Two dams were constructed at the saltwater and fresh-water inlets. The pit was approximately 600 ft in diameter and 320 ft deep.

Approximately 5 million tons of non-ore-bearing waste rock were removed from the mine and stored in piles throughout the property. Approximately 800,000 tons of ore-bearing rock removed from the mine during open pit excavation was processed through a series of crusher mills and minerals removed using the flotation process. Sediment laden water from the crushing process was discharged directly into Goose Cove through a 16-inch pipeline. The remaining nonmineral particles and residues of the chemical reagents from the flotation process were discharged as a slurry to an 11-acre tailings pond on site. Mining and milling operations ceased in 1972.

USEPA completed a Human Health and Ecological Risk Assessment, which revealed the presence of copper, lead, and zinc in sediments of Goose Pond at levels acutely toxic to benthic organisms. Metals were found to be accumulating in biota at the site and food chain modeling identified sediments in Goose Pond and the adjacent salt marsh as a threat to insect and fish-eating birds. Surface water also contains metals at concentrations that could adversely impact aquatic organisms.

In 2010, USEPA separated the OU 1 Record of Decision activities into two components. The sediment and waste rock excavations, disposal in the CAD cell, and the system for the tailings impoundment will be addressed in OU 3.

CSM summary: There are six primary contaminant source areas at the site (the tailings pile, three waste rock piles, the ore pad, and the former operations area) and four secondary contaminant source areas (Dyer Cove, Goose Pond, the former mine pit, and Goose Cove). The release mechanisms are acid rock drainage and leaching of metals to groundwater and surface water, erosion, windblown dust, and slope failure. Potential receptors include ecological and human. Metals have been found to be accumulating in biota and food chain modeling identified sediments in Goose Pond to be a threat to insect and fish-eating birds. The site is not enclosed and unauthorized recreational use leaves the potential for human contact with contaminated soil, sediment, and surface water.

A.6.4 Remedial Objectives

RAOs/project objectives for this site include:

- Prevent exposure of biota to sediment including the sediment/soil in the salt marsh, with concentrations of copper, lead, or zinc that may represent a threat to insectivorous and piscivorous birds, fish, and other aquatic organisms.
- Minimize impacts from waste rock and tailings within the OU 3 area on groundwater, surface water, and sediment.
- Stabilize the tailings impoundment to achieve acceptable stability criteria.
- Comply with the applicable or relevant and appropriate federal and state regulations that apply to the cleanup action.

A.6.5 Remedial Approach

The proposed remedy for this site includes the following tasks:

- Excavate waste rock/source materials and dispose of the excavated material in a CAD cell in the former mine pit.
- Dredge the Southern Goose Pond mine and adjacent salt marsh with disposal of waste in the CAD cell.
- Cap and stabilize the tailings impoundment with surface water diversion around a horizontal drain within the tailings impoundment.
- Install a wetlands treatment system to treat the discharge of contamination from the horizontal drain that will be installed within the tailings impoundment.
- Impose land use restrictions to prevent disturbance of the cap, wetlands treatment system, and CAD cell.
- Restore disturbed areas, including wetlands, and the possibility remove mine waste in Goose Cove and Goose Pond as part of the wetland mitigation activities.

The remedy is likely still in the early proposal stage and was separated out from OU 1 to make up OU 3 in 2010.

A.6.6 References

USEPA Waste Site Cleanup & Reuse in New England, Callahan Mining Corp. http://yosemite.epa.gov/r1/npl_pad.nsf/701b6886f189ceae85256bd20014e93d/584c38df37ade1998525764f005a96d3!OpenDocument.

A.7 Columbia Slough, OR

A.7.1 Contacts

Jennifer Sutter
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2020 SW 4th Ave, Suite 4000
Portland, OR 97201
503-229-6148
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A.7.2 Summary

Environment:	Freshwater slough
Scale:	Full
Contaminants of Concern:	Stormwater discharges, DDT/DDE, dieldrin, dioxins, PCBs, and lead
Source Control Achieved Prior to Remedy Selection?	Source control implemented as part of remedy
Final Remedy:	Source control, hotspot removal (dredging), and MNR

A.7.3 Site Description

The Columbia Slough watershed drains approximately 32,700 acres of land encompassing 31 miles of waterway just south of the Columbia River. In addition to the city of Portland, the watershed includes Fairview Lake and Fairview Creek, and portions of Troutdale, Fairview, Gresham, Maywood Park, Wood Village, and Multnomah County. Over 50 individual sites have been identified and are in various phases of the remedial process. Primary sources of contamination at this site include soil erosion via surface runoff, contaminated groundwater discharges, and direct discharge into the slough from municipal stormwater systems that received stormwater from private, commercial, and industrial facilities.

The watershed once contained a system of side channels, lakes, and wetlands that comprised the floodplain of the Columbia River between the mouths of the Willamette and Sandy Rivers. High water seasonally inundated the floodplain, cutting new channels and depositing sediment. Native Americans used these waterways and the uplands for fishing, hunting, and gathering food.

Over the years, the watershed and waterway have been drastically altered. Beginning in 1918, levees were built and wetlands were drained and filled to provide flood protection and allow for development. The waterway was channelized, and dozens of streams were diverted from natural channels to underground pipes. Today the Columbia Slough comprises a 19-mile main channel that parallels the Columbia River, as well as approximately a dozen additional miles of secondary waterways. Other remaining major surface water features include Fairview Creek, Fairview Lake, and Smith and Bybee Lakes. Floodplain development has resulted in an extensively managed surface water system that includes levees, pumps, and other water control structures in the Middle and Upper Sloughs. The levee system greatly reduced the Columbia River's connection to its flood-plain.

The Slough is currently divided into three sections, based on hydraulic characteristics:

- The Upper Slough starts at the mouth of Fairview Lake on the east and flows west to the mid-dike levee at NE 142nd Avenue. It includes Big Four Corners East & West Sloughs. It receives water from Fairview Lake, Fairview Creek, Wilkes Creek, stormwater outfalls, natural springs, groundwater, and overland flow.
- The Middle Slough extends from the mid-dike levee, near NE 142nd Avenue to the Pen 2 levee, near NE 18th Avenue. It includes a substantial southern arm complex of sloughs and lakes, including Peninsula Drainage Canal, Prison Pond, Mays Lake, Johnson Lake, Whitaker Slough, Whitaker Ponds, and Buffalo Slough. The Middle Slough receives water from the Upper Slough, stormwater outfalls, natural springs, groundwater, and overland flow. Pumps are used to move water from the Upper and Middle Slough to the Columbia River or the Lower Slough.
- The Lower Slough starts at the Pen 2 levee, near NE 18th Avenue, and extends approximately 8.5 miles to the Willamette River. The lowlands of the Lower Slough Watershed are subject to flooding because they are not protected by levees. Water flow and levels in the Lower Slough are affected primarily by the Columbia River and Willamette River and the ocean tides, and to a lesser extent by pumping. During high tide, the Columbia and Willamette Rivers create a backwater effect that complicates flow patterns.

The Columbia Slough Watershed now includes several types of land uses: residential neighborhoods, commercial and industrial development, agriculture, Portland International Airport, interstate highways, railroad corridors, and large open spaces. Much of Portland's industrial and commercial land is located within the watershed. In addition to industrial development in the area north of Columbia Boulevard and the Rivergate area, land is preserved for industrial uses in the Columbia South Shore area between NE 82nd and NE 185th Avenues north of Sandy Boulevard.

Over time, extensive alteration of the Slough's watershed, due to industrial and residential development, has had a deleterious effect on the environmental quality of the watershed. As development occurs, the natural topography, hydrology, and vegetation are altered and impervious surfaces such as streets, parking lots, and buildings are placed over much of the land. As a result of urbanization, industrial releases, alteration of water flows, and runoff from agricultural land, the Columbia Slough has polluted water, sediments, and fish.

A.7.4 Remedial Objectives

Concerns for this case study include both ecological and human health risks associated with mercury. The sediment cleanup action objectives' focus is on achieving compliance with cleanup standards in surface sediments of the bioactive zone (40 mg/kg, Washington State Department of Ecology sediment quality standard). These are defined in the 2007 Cleanup Action Plan.

A.7.5 Remedial Approach

Final selected remedy: Unique aspect of this site is the watershed-based remedial approach developed in the 2005 ROD consisting of source control, hot spot cleanup, and natural recovery.

- Source control—implementing actions that address the sources of contamination to reduce contaminant inputs. Addressing the sources of contamination is important because it will prevent recontamination of remediated sediments and allow natural recovery processes to effectively reduce existing contamination in the slough.
- "Hot spot" cleanup—dredging sediments that are contaminated at levels that exceed the general pervasive level of contamination throughout the slough.
- Long-term monitoring—evaluate the effectiveness of the actions taken and identify areas where more focused attention is necessary.

Source Control Actions in Progress:

- Blasen site located at 1601 N. Columbia Boulevard.
- Upland and bank cleanup was initiated at the Pacific Meat site located at 2701 N Newark Street.
- Upland source control remedy is pending at the Wastech site located at 701 Hunt Street.

Cleanup Action Selected:

- A feasibility study was completed and remedial action proposed for the Fuel Processors, Inc. site located at 4150 N Suttle Road.
- Upland source control remedy was selected at the Precision Equipment site located at 8440 N. Kerby Avenue.
- Upland stormwater source control remedy selected for the Portland Willamette site located at 6800 NE 59th Avenue.

Upland Cleanup Completed:

- Surface soil cleanup was completed at the Carco site located at 900 N Columbia Boulevard.
- Metal-contaminated soil was removed at the Macadam Aluminum and Bronze site just west of I-5 and the storm drain system was cleaned and replaced.
- Monitoring at the ICN Pharmaceuticals site located at 6060 NE 112th Avenue was completed and the site was removed from DEQ's confirmed release list and inventory.

A.7.6 Monitoring

Long-term Monitoring

The Columbia Slough Watershed Long-Term Monitoring Plan (LTMP) describes monitoring that the U.S. Department of Energy, Office of Basic Energy Sciences (BES) will conduct in the Slough Watershed over the next ten years and beyond. This is a dynamic plan, and as technology and monitoring approaches change, the LTMP will also be changed to reflect those changes. The following highlights fiscal year 2010 Columbia Slough long-term monitoring efforts.

Sediment Monitoring

Sediment sampling was conducted by the city in 2006. A report documenting this sampling event is available on the city web page. Data from this sampling event is being combined with data collected in the DEQ sampling, private party cleanup site sampling, MCDD sampling for channel maintenance, and ODOT sampling for bridge construction into a slough sediment database that will be used to determine data gaps and plan remedial measures.

No slough-wide sediment sampling is planned for the next year. In-line sediment sampling in the MS4 in the Marx-Whitaker and/or I-5 to MLK target areas may be conducted.

Initial Water Quality Monitoring

Water quality samples were taken at nine sites throughout the Columbia Slough. Continuous, 15 minute, samples were taken for temperature, pH, conductivity, and dissolved oxygen. Grab samples were taken bi-monthly and analyzed for the following analytes/parameters:

- Chlorophyll a
- Biological oxygen demand (5 day, BOD-5)
- Conductivity (specific)
- Copper (total and dissolved)
- Flow Direction and velocity
- Dissolved oxygen
- E. coli
- Hardness (total)
- Lead (total and dissolved)
- Mercury
- Nickel (total and dissolved)
- Nitrogen (ammonia, nitrate and total Kjeldah)
- pH
- Phosphorus (total and ortho phosphate)
- Secchi disc
- Temperature
- Total suspended solids
- Zinc (total and dissolved)

Ongoing Water Quality Monitoring

Continuous water quality monitoring of at least three Columbia Slough sites will continue as in past years, and a fourth site will be added again once the Vancouver Avenue bridge restoration is completed. Continuous monitoring measurements include temperature, pH, conductivity, and dissolved oxygen. A water quality report summarizing sample results over the past five years is under development by the city and will be submitted to DEQ in 2011.

The City of Portland is updating its watershed monitoring approach. The city's new surface water quality monitoring program, Portland Area Watershed Monitoring and Assessment Program (PAWMAP), incorporates the best available science and protocols developed by the national Environmental Monitoring and Assessment Program (EMAP). The PAWMAP program includes spatially-balanced random selection of stream survey sites. Elements to be monitored address all four watershed health goals (hydrology, habitat, water quality, and biological communities), and the effort will be expanded to include systematic monitoring of terrestrial habitat. In addition, the new approach will increase the rigor, accuracy, and cost-efficiency by streamlining efforts and coordinating to fulfill many of the city's compliance monitoring requirements. The new monitoring program was designed in 2009 and began implementation in the summer of 2010. The first year of monitoring will establish baseline data against which future years' results can be compared to measure changes in watershed health.

For fiscal year 2011, five perennial sites have been selected in the Columbia Slough. These sites will be monitored quarterly during dry weather and once during wet weather. Grab samples will be collected for the following analytes:

- Alkalinity
- Chlorophyll a
- BOD-5
- Carbon, dissolved organic (summer only)
- Carbon, total organic
- Conductivity (specific)
- Copper (total and dissolved)
- Dissolved oxygen
- E. coli
- Hardness (total)
- Physical Habitat Monitoring
- Lead (total and dissolved)
- Mercury, total
- Nitrogen (ammonia, nitrate, nitrite, and total Kjeldahl)
- pH
- Phosphorus (total and ortho-phosphate)
- Temperature
- Turbidity
- Total suspended solids
- Zinc (total and dissolved).

PAWMAP also includes physical habitat monitoring using EMAP National Streams and Rivers Assessment protocols. Each of the five perennial slough sites will be surveyed each year. The surveys will be conducted July through September during dry weather. Physical habitat indicators evaluated through stream surveys include the following:

- Large wood
- Depth refugia zone
- Substrate composition
- Amount of off-channel habitat
- Bank condition
- Stream connectivity
- Bio-Monitoring
- Width and composition of vegetated riparian
- Breaks and barriers
- Plant community composition
- Floodplain condition
- Canopy cover

BES will continue monitoring a variety of species of concern. Some of the species are on the federal Threatened and Endangered list and some are on the State of Oregon list of sensitive species. BES will conduct quarterly fish monitoring at the slough's confluence with the Willamette River. BES will also monitor birds, amphibians, turtles, and macrophytes at various sites in the slough watershed.

Bio-monitoring is also conducted as part of PAWMAP and includes the following: fish (quarterly) and benthic macroinvertebrates (annually).

Stormwater Monitoring

DEQ and the city plan to develop a contaminant-loading model that will estimate the type and concentration of pollutants associated with stormwater runoff. The results of this study will be used to identify outfalls where source control measures appear to be warranted and to determine when adequate source control measures have been completed.

Costs: DEQ has developed a process through which private parties can get release from liability for sediment cleanup by contributing to a fund managed by DEQ. Payment is based on the site's likely contribution to sediment contamination. DEQ has accumulated > $2 million via this option and has used it to collect data in two priority areas in the slough using a combination of MIS and discrete sediment sampling. Parties can also opt for release from state natural resource damage claims by contributing to a separate fund to be used for habitat enhancement projects.

RAOs/project objectives achieved?: The completed objectives are noted in the discussion of the remedial approach (Section A.7.5). The city is conducting long term monitoring of environmental conditions including wide spread fish tissue and sediment sampling conducted every 10 years. Baseline samples were collected in 1995, and the first 10-year samples were collected in

2005/2006. DEQ has worked with the city to lay out Watershed Action Plan describing watershed-wide source control efforts. DEQ is working with individual parties to ensure source control is implemented at specific sites.

A.7.7 References

Portland Bureau of Environmental Services Columbia Slough Program. http://www.-portlandonline.com/bes/index.cfm?c=49910&.

Columbia Slough Sediment Analysis Report 2006 Sampling. http://www.-portlandonline.com/bes/index.cfm?c=49910&a=234746.

The State of the Slough: 2010 Annual Report Columbia Slough Sediment Project. http://www.-portlandonline.com/bes/index.cfm?c=49910&a=335382.

A.8 Commencement Bay, WA

A.8.1 Contact

Regulatory Contact: USEPA

A.8.2 Summary

Environment:	Marine embayment
Scale:	Full
Contaminants of Concern:	Metals (arsenic, lead, zinc, cadmium, copper, mercury), PCBs, PAHs, volatile organic compounds (VOCs), and phthalates
Source Control Achieved Prior to Remedy Selection?	No
Final Remedy:	MNR (60 acres), capping and dredging (240 acres)
Expected Recovery Time:	10 years

A.8.3 Site Description

The Commencement Bay Nearshore/Tideflats site is located in the southern end of the main basin of Puget Sound in the City of Tacoma and the Town of Ruston, Washington. There is an active commercial seaport on site that includes 10-12 square miles of shallow water, shoreline, and adjacent land. The majority of the area is highly developed and industrialized. Primary sources of contamination at this site include past and present wastewater discharges from numerous and varied industrial operations, as well as past and present nonpoint contributions to the watershed.

Various industrial activities have been operating in the vicinity since the turn of the century including shipbuilding, oil refining, chemical manufacturing and storage, and pulp and paper mills. Currently 281 industrial facilities are active in the site. 34 of these have NPDES permits for storm drain, seep, and open-water discharges; groundwater seepage; atmospheric deposition; and spills. In addition, the Tacoma-Pierce County Health Department identified several hundred nonpoint sources that discharge to Commencement Bay as well as 70 facilities that are ongoing contaminant sources. This site was added to the National Priorities List in 1983.

CSM summary: Primary natural recovery processes at this site include physical isolation, chemical transformation and dispersion. Lines of evidence collected to support these natural recovery processes include sediment traps to determine source controls and sediment inputs, sediment core profiling and radioisotope analyses to determine key fate and transport processes as well as document historical recovery rates. Models were then used to interpret this data and estimate sediment concentrations over a 10 year period.

A.8.4 Remedial Objectives

The primary concern for this case study is human health and ecological risk from PCBs, PAHs, 4-methylphenol, and VOCs.

The RAO/project objective for this site is "to achieve acceptable sediment quality in a reasonable time frame." "Acceptable sediment quality" is defined as "the absence of acute or chronic adverse effects on biological resources or significant human health risks." A "reasonable time frame" is defined as within 10 years following the completion of dredging and/or capping operations.

A.8.5 Remedial Approach

Final selected remedy: MNR (60 acres); capping and dredging (240 acres)

MNR was selected for several sites in the Commencement Bay Nearshore/Tideflats area including Hylebos Waterway, Area B of Sitcum Waterway, Middle Waterway, Thea Foss and Wheeler-Osgood Waterways. In addition, MNR would be accelerated if more contaminated sediments in the area were removed. The various components of these remedies include:

- evaluation and control of upland sources of contamination
- removal of sediments with chemical concentrations high enough to be internal sources of recontamination
- capping areas of high concern for adverse biological effects or potential contamination from resuspension and bioaccumulation
- MNR or EMNR with thin-layer caps in areas of moderate concern
- institutional controls (such as limits on fish or shellfish consumption and anchorage restrictions).

Primary lines of evidence used to investigate MNR: Modeling was used to support determinations of physical isolation, chemical transformation and dispersion. The models took into account additional mass deposition from ongoing sources, sediment deposition, and bioturbation.

A.8.6 Monitoring

Monitoring elements: Monitoring activities aim to assess the performance of natural recovery processes and RAO attainment. Lines of evidence to support physical isolation include sediment coring and vertical profiling, radioisotope analysis, and sediment age dating and surface sediment chemistry and grain size analysis. Lines of evidence that support chemical transformation include PAH fingerprint analysis to assess vertical/lateral profiles and trends in chemical transformation. Lines of evidence collected to support risk reduction include the visual inspection of exposed tideflats to document benthic burrowing activity and biota tissue analysis.

Expected recovery time: 10 years

Projected monitoring costs: $310,000

RAOs/project objectives achieved? Overall MNR is viewed as a success where sufficient monitoring data have been collected (Sitcum Waterway). For Area B of the Sitcum Waterway, cleanup levels have been achieved with natural recovery. The long-term monitoring was deemed complete in 2004. Baseline monitoring has been completed and long-term monitoring is planned to begin in 2008 for the Theo Foss and Wheeler-Osgood Waterways.

A.8.7 References

USEPA Region 10, the Pacific Northwest: Commencement Bay-Nearshore Tideflats. http://yosemite.epa.gov/r10/cleanup.nsf/sites/cbnt.

A.9 Detroit River, Black Lagoon, Trenton, MI

A.9.1 Contacts

Regulatory Contacts: Great Lakes National Program Office and Michigan Department of Water Quality

A.9.2 Summary

Environment:	Off-channel freshwater embayment
Scale:	Full
Contaminants of Concern:	PCBs, oil and grease, mercury, heavy metals
Final Remedy:	Dredging and placement in Pointe Mouille Confined Disposal Facility
Expected Recovery Time:	30 years

A.9.3 Site Description

The Black Lagoon is a small off-channel embayment located within the Trenton Channel of the Detroit River. The site is located adjacent to Mary Ellias Park in Trenton, MI. The site is located within the Detroit River Area of Concern (AOC). The Detroit River AOC is a binational AOC which drains approximately 700 square miles of land in Michigan and Ontario, including the city of Detroit, MI. Primary sources at this site include historical contamination from upstream industries.

The McLouth steel mill, located approximately one-half mile north of the site, closed in 1995 and is considered the primary source of sediment contamination in the Black Lagoon. CSOs, municipal and industrial discharges, and stormwater runoff may also have contributed to sediment contamination within the Black Lagoon. These impacts included the lagoon's reduced capacity to support recreational activities such as swimming, fishing, and boating, as well as impairment of lagoon aesthetics from oil floating on the water surface. The health of the aquatic life in the water and sediments of the Black Lagoon, as well as wildlife along the shoreline, also were adversely affected by the pollution. The Black Lagoon proposal was the first project to be accepted and funded under the Great Lakes Legacy Act (GLLA) of 2002.

A.9.4 Remedial Objectives

Elevated levels of PCBs, mercury, and oil and grease were determined to pose a risk to the health of the benthic community. Two primary remedial objectives were established:

- Reduce relative risk to humans, wildlife, and aquatic life.
- Restore the aquatic habitat within the Black Lagoon.

A.9.5 Remedial Approach

Final selected remedy: dredging followed by off-site disposal in a confined disposal facility.

Dredging was selected because a suitable disposal site was available and to facilitate revitalization of the off-channel embayment and adjacent upland properties. Because this work was completed under the GLLA, a feasibility study was not performed.

Dredging operations were undertaken with the goal to dredge to hardpan across the lagoon. Prior to dredging, a silt curtain was installed to enclose the entire lagoon and protect the adjacent river from releases of suspended sediments during dredging operations. Using a clamshell dredge device, approximately 103,500 yd^3 of contaminated sediments were removed. After completion of this first round of dredging, the remaining residual sediments were sampled and analyzed to verify that the dredging activities reduced contamination to acceptable levels. Results of these analyses suggested that high concentrations of the contaminants of concern still remained in some areas, so a second phase of dredging (Phase II) was conducted to remove an additional 1–3 ft of sediment.

Sampling after Phase II of dredging indicated that, although contaminants were still present in some areas above originally targeted levels, the second round of dredging successfully reduced both the overall concentration and the distribution of those contaminants. In all, approximately 115,000 yd^3 of contaminated sediments containing approximately 478,000 pounds of PCBs, mercury, oil and grease, lead, and zinc were removed from the lagoon. After removing the contaminated sediments, a sand and stone cover was installed. The cover consisted of at least 6 inches of clean sand that was further covered by 4 to 6 inches of stone. The primary purpose of the cover was to provide a barrier between the benthic community and any residual contaminated sediment. This cover will enhance natural attenuation, add habitat for regrowth of healthy organisms on the lagoon floor, and reduce exposure of fish to contamination through consumption of bottom dwelling organisms.

A.9.6 Monitoring

The original plan was based on the assumption that dredging activities would remove all or most of the sediments, and along with them, all or most of the contaminants of concern. The contaminants of concern, however, were still present at high levels after the first round of dredging operations. These higher than expected concentrations, along with deeper than expected post-dredge sediment depth measurements, confirmed suspicions that the original sediment depth estimates were incorrect. After reviewing the new sediment depth and contaminant data, a second phase of dredging was deemed necessary and samples were collected based on new criteria. Results suggest that, although the Phase II dredging activities did not completely reduce contaminant concentrations to the levels targeted, the second round of dredging was successful in reducing both the overall concentration and the distribution of those contaminants.

Although dredging efforts in the Black Lagoon dramatically reduced the levels of contamination across the site, the target cleanup levels were not achieved. As a result a residual cover was installed to isolate any remaining contaminated sediments. The residual cover consisted of at least 6 inches of sand and 6 inches of gravel installed to trap the underlying sediment and provide a clean habitat for benthic communities. After the deposition of the sand layer, 18 additional sediment confirmation samples were collected. Sampling in the sand cover is an environmental verification technique that is kept to a minimum, to maintain the residual cover's integrity and prevent mixing the underlying sediment with the clean cover.

Expected recovery time: 30 years

Costs: The $8.7 million Black Lagoon remediation project was funded with $5.6 million from GLNPO under the GLLA and $3.1 million in non-federal matching funds from the MDEQ.

The project successfully leveraged GLLA funding to complete a sediment cleanup. Although generated residuals prevented attainment of the target cleanup levels, the placement of a sand cover allowed the overall project objectives to be met. The project then served as a catalyst for site redevelopment. Subsequent to completion of the removal action, the City of Trenton was awarded $151,000 for shoreline habitat restoration. In June 2007, the City of Trenton received a

$582,000 boating/infrastructure grant from the U.S. Fish and Wildlife Service for marina construction/boating access and is matching that grant with $200,000 to construct floating docks and boat access at the site.

RAOs/project objectives achieved? Through dredging and placement of the residual cover, the project objectives were achieved. In 2007, the City of Trenton and its many partners celebrated the restoration and revitalization of the Black Lagoon in a ceremony renaming Black Lagoon as Ellias Cove, in honor of the family who donated the adjacent land (Meyer-Ellias Park) to the City of Trenton.

A.9.7 References

USEPA Black Lagoon Legacy Act Cleanup Detroit River Area of Concern. http://www.epa.gov-/glla/blklagoon/index.html.

Remediation of the Black Lagoon; Trenton, Michigan; Great Lakes Legacy Program. http://www.epa.gov/glla/blklagoon/BlkLagoonRpt032009.pdf.

A.10 Eagle (East) Harbor, Wycoff, WA

A.10.1 Summary

Environment:	Marine
Scale:	Full
Contaminants of Concern:	Residue from wood treating facility: creosote, PCP, PAHs. Heavy metals: mercury, lead, copper, zinc
Final Remedy:	• Sediments were dewatered on an asphalt-treated base work area pad, which drained into a sump that was pumped to storage tanks. • Removal and disposal were in an on-site CDF of hotspot sediments containing more than 5 milligrams per kilogram (mg/kg) total mercury. • Materials greater than two inches in diameter were disposed of off site at Olympic View Landfill.

A.10.2 Site Description

Wycoff, WA

Year: 1997

Water Depth: 15–45 ft

Target Volume: Projected Mercury impacted area: 1,500–9,000 yd^3

A.10.3 Remedial Objectives

- anthracene 1,200 mg/kg
- chrysene 460 mg/kg
- naphthalene 170 mg/kg
- pyrene 1,400 mg/kg
- mercury 0.58 mg/kg

Contaminated sediment thickness: up to 0.7 yards deep

A.10.4 Remedial Approach

Dredged using front end loader and clamshell bucket. Sediments were dewatered on an asphalt-treated base work area pad, which drained into a sump that was pumped to storage tanks. Materials greater than 2 inches in diameter were disposed of off site at Olympic View Landfill.

Removal and disposal in an on-site CDF of hotspot sediments containing more than 5 milligrams per kilogram (mg/kg) total mercury.

Demolition and removal of buildings, structures, above and underground storage tanks, underground foundations and piping, and removal of asbestos, sludge, and heavily contaminated soil.

New aquatic habitat constructed to mitigate loss of 0.9 acres from remedial construction.

A.10.5 Monitoring

Resuspension during dredging operation. No details on resuspension controls for this site. Most activities were performed at extreme low tide. Sheet piling was used to withhold water from the dredging areas.

Performance:

Goals were met. Concerns exist for future protectiveness of habitat/water quality.

Residuals:

All dredged areas backfilled with clean sediment to pre-existing grade elevations.

Placement of thick cap (1 meter) over sediments containing >2.1 ppm mercury; and placement of thin cap (15 centimeters) over sediments exceeding chemical or biological cleanup standards.

PAH intertidal area monitored for 10 years to allow natural recovery.

A.10.6 References

Declaration for the Record of Decision. http://web.cecs.pdx.edu/~fishw/ECR_Wyck-offEagleSumm.pdf.

USEPA Five-Year Review Report Wyckoff/Eagle Harbor Superfund Site. Sep 2002. http://www.epa.gov/superfund/sites/fiveyear/f02-10002.pdf.

U.S EPA. Second Five-Year Review Report for the Wyckoff/Eagle Harbor Superfund Site Bainbridge Island, Washington. Sep 2007. http://www.epa.gov-/superfund/sites/fiveyear/f2007100001727.pdf.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.11 East Doane Lake, Port of Portland, OR

A.11.1 Summary

Environment:	Freshwater
Scale:	Field
Contaminants of Concern:	Lead, dioxin
Final Remedy:	Debris removed, dredging then disposal to an on-site, dedicated RCRA containment cell then deposited in a new on-site landfill, which was constructed in 1999.

A.11.2 Site Description

The East Doane Lake site was owned by Gould Inc. and was contaminated with lead and dioxin. The contaminated sediment area consisted of a 3.1-acre lake remnant.

A.11.3 Remedial Objectives

Removal of contaminated sediment averaging 2 ft deep, with a dredge depth of 1–5 ft.

A.11.4 Remedial Approach

A horizontal auger dredge was used for sediment removal. The lake contained extensive industrial debris, including cables, batteries, gas cylinders, concrete blocks, and tires. Most large items were removed by divers before dredging began. The target removal volume of sediments was 6,000 yd^3; the actual volume removed was 11,000 yd^3

A.11.5 Monitoring

Residuals concentrations were significantly lower after dredging. The lake was backfilled with 95,000 tons of rock.

A.11.6 References

U.S. EPA. Superfund Information Systems Five-Year Reviews Online Gould, Inc. as updated Feb. 2008. http://cumulis.epa.gov/fiveyear/index.cfm?fuseaction=fyrsearch.showSitePage&id=1000455.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.12 Formosa Plastics, TX

A.12.1 Summary

Environment:	Marine
Scale:	Full
Contaminants of Concern:	Ethylene dichloride
Final Remedy:	Site was partially dewatered by cofferdam. Partially dewatered sediment was placed on barges and mixed with 10% cement to off-load and dispose. Disposal at 2 hazardous waste landfills. One was 264 miles away; the other was 105 miles away.

A.12.2 Site Description

The site is located in Texas, and contaminated sediments consisted of 6–12 ft of soft, silty bay floor underlain by thick, high plasticity clay.

Year: 1992

Water Depth: 25–30 ft

Target Volume: 3,300 yd^3

Actual Volume Removed: 7,500 yd^3

A.12.3 Remedial Objectives

Ethylene dichloride: 500 ppm

Remedial area: Area of 150 by 350 ft in corner of an active turning basin, 1.1 acre.

A.12.4 Remedial Approach

Wet hydraulic dredging did not work. The site was excavated with a barge- mounted crane and environmental bucket. Hydraulic dredging was the planned method of excavation, but due to severe water capacity limitations on land, mechanical dredging was performed. Concern over dredging causing even more erosion to channel stabilization. Active dredging periodically halted due to traffic.

Soft silty sediments kept "running into" the hot spot from the surrounding areas. Surface-to-bottom silt curtains with anchors on bottom were installed, and anchor cages were added to hold top of curtain in place.

Two passes were required because the first pass, using the hydraulic method, did not work effectively.

A.12.5 Monitoring

RAOs/project objectives achieved?: Project met all goals at all locations. No capping or backfill was needed at this site for residuals.

A.12.6 References

Agency for Toxic Substances & Disease Registry as updated Oct 2009. Preliminary Public Health Assessment Alcoa (Point Comfort)/Lavaca Bay. http://www.atsdr.cdc.gov/HAC/pha/pha.asp?docid=46&pg=3.

U.S. EPA. Performance-Based Remedy Decision Document. Oct 2009. http://www.epa.gov/region6/6pd/rcra_c/pd-o/final_dd-fpctx100909.pdf.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.smwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.13 Fox River and Green Bay, WI 1998

A.13.1 Summary

Environment:	Freshwater
Scale:	Pilot
Contaminants of Concern:	PCBs, 45 ppm avg,186 ppm max, Mercury
Final Remedy:	Hydraulic cutterhead with swinging ladder used to dredge and sediment was dewatered, filtered. 905 tons (<50 ppm) taken to Winnebago County Landfill; 1,632 tons taken to E.Q. landfill (>50 ppm PCBs); 2,400 tons taken to Wayne Disposal.

A.13.2 Site Description

Year: 1998

Water Depth: 0–8 ft

Target Volume: 12,000 yd^3 sediment

Actual Volume Removed: 8,200 yd^3

Contaminated thickness: 2–3 ft

A.13.3 Remedial Objectives

Mass removal, demonstration

A.13.4 Remedial Approach

A hydraulic cutter head with a swinging ladder configuration was used. More minor dredging was done in 1999 to remove additional sediment at bedrock interface.

A.13.5 Monitoring

Resuspension: Six turbidity meters in river dredging area. Perimeter barrier of 80 mil HDPE, silt curtain around dredge sub-areas, 200 foot-long HDPE "deflection" barrier around industrial water intake, double-cased dredge discharge line.

Residuals: Post dredging: Surface sediments: 0.04–43 ppm PCBs, 16/19 samples >2 ppm. In 13/21 samples, post-dredge concentrations higher than pre-dredge

A.13.6 References

United States of America and The State of Wisconsin v. Appleton Papers Inc. and NCR Corporation Consent Decree. http://foxrivercleanup.com/bmos-resources/consentdecree801.pdf.

Record of Decision Operable Unit 1 and Operable Unit 2 Lower Fox River and Green Bay, Wisconsin Record of Decision Responsiveness Summary. Dec 2002. http://foxrivercleanup.com/bmos-resources/rod1.pdf.

Record of Decision Amendment Operable Unit 2 (Deposit DD), Operable Unit 3, Operable Unit 4, and Operable Unit 5 (River Mouth). June 2007. http://foxrivercleanup.com/bmos-resources/amendedrod.pdf.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.smwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.14 Fox River and Green Bay, WI 2002

A.14.1 Summary

Environment:	Freshwater
Scale:	Full
Contaminants of Concern:	PCBs, 54 ppm avg., metals (mercury), PAHs
Final Remedy:	Hydraulic auger used to dredge material. Material taken to Fort James landfill, six miles away. Sediment isolated in separate cell and monitored for leachate for life of landfill.

A.14.2 Site Description

Year: 2002

Project 1 SMU 56/57

Water Depth: 2–14 ft

Target Volume: 92,000 yd^3

Actual Volume Removed: 81,816 yd^3 (9 acres)

A.14.3 Remedial Objectives

- SWAC, Upper four inches, PCB concentration of 1 ppm or less.
- SWAC, PCB concentration of 10 ppm or less, with six-inch sand layer backfill.

A.14.4 Remedial Approach

Hydraulic auger for dredging. Dredge replaced several times due to lack of effectiveness. Several different dredges used, and two dredging passes were required (1999 and 2000).

Silt curtains used. Several times, perimeter silt curtains were dislodged or torn by currents. Curtains required significant maintenance throughout; therefore sheet piling placed at area corners for stable anchoring.

The entire dredge site was backfilled with a 9–12 inch sand layer.

A.14.5 Monitoring

Post dredging results were as follows:

- 11 of 28 samples <1 ppm
- 24 of 28 samples <4 ppm
- Average, 2.2 ppm with range of ND-9.5 ppm

A.14.6 References

Fox River Cleanup Group. http://foxrivercleanup.com/documents/.

USEPA. First Five-Year Review Report for Fox River NRDA/PCB Releases Site. July 2009 http://www.epa.gov/superfund/sites/fiveyear/f2009050002959.pdf.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.15 Fox River and Green Bay, WI 2009

A.15.1 Summary

Environment:	Freshwater
Scale:	Full
Contaminants of Concern:	PCBs, max 222 ppm, dioxin, furan, DDT, heavy metals
Final Remedy:	Swinging ladder dredge used. Non-TSCA sediments taken to Onyx Hickory Meadows Landfill (27 miles).

A.15.2 Site Description

Year: 2009

Water depth: 6–20 ft

Target volume: 748,200 yd^3

Actual volume removed: approximately 500,000 yd^3

Contaminated sediment depth: 1–6 ft

Contaminated sediment area: 39 miles

A.15.3 Remedial Objectives

- PCBs: 1.0 ppm
- SWAC of 0.25 ppm PCBs in the upper 10 cm of sediment

A.15.4 Remedial Approach

A swinging ladder dredge was used. Another 245,000 yd^3 were capped. Silt curtains were placed at both the spreader bay and discharge line to control suspended solids.

A.15.5 Monitoring

Post dredging average PCB concentration were 0.23 ppm. A six-inch sand cap was placed on areas where 1.0 ppm of PCBs were not reached.

RAOs/project objectives achieved? Yes.

A.15.6 References

Final Basis of Design Report Lower Fox River and Green Bay Site Volume I. Jun 2006. http://-foxrivercleanup.com/bmos-resources/basisofdesignreportvolume1.pdf.

Record of Decision Operable Unit 1 and Operable Unit 2 Lower Fox River and Green Bay, Wisconsin Record of Decision Responsiveness Summary. Dec 2002. http://-foxrivercleanup.com/bmos-resources/rod1.pdf.

Record of Decision Amendment Operable Unit 2 (Deposit DD), Operable Unit 3, Operable Unit 4, and Operable Unit 5 (River Mouth) Lower Fox River and Green Bay Superfund Site. June 2007. http://foxrivercleanup.com/bmos-resources/amendedrod.pdf.

U.S. EPA. First Five-Year Review Report for Fox River NRDA/PCB Releases Site. July 2009. http://www.epa.gov/superfund/sites/fiveyear/f2009050002959.pdf.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.16 Fox River and Green Bay, WI 2013

A.16.1 Summary

Environment:	Freshwater
Scale:	Full
Contaminants of Concern:	PCBs, OU 2: >50 ppm, OU 3: >50 ppm, OU 4: >50 ppm, OU 5: >1.0ppm, Dioxin, Furan, DDT heavy metals: arsenic, lead, and mercury Dioxin, furan, DDT, and heavy metals not targeted.
Final Remedy:	Disposal information will be defined once dredging has begun. The proposed plan is to dewater the sediment and transport dried sediment to off-site landfills in Illinois or Michigan.

A.16.2 Site Description

Year, projected:

- OUs 2 and 3: 2013
- OUs 4 and 5: 2017

Water depth: 6-20 ft

These sites contain 12 dams and 17 locks. The contaminated sediment areas are 33 miles and 1,600 sq. miles, respectively.

Target Volume, total combined: 3.5 million yd^3

Contaminated sediment depth:

- OU 2: 40 inches of sediment
- OU 3: 7.5 ft

- OU 4: 13 ft.

A.16.3 Remedial Objectives

- PCBs: 1.0 ppm
- SWAC of 0.25 ppm PCBs in the upper 10 cm of sediment

A.16.4 Remedial Approach

Mechanical dredging will be used. OU 2 (Appleton to Little Rapids Dam. 20 mile stretch) and OU 5 (1,600 miles of Green Bay) will use MNR.

A.16.5 Monitoring

Resuspension: The extent of dredging will be monitored for resuspension and measures may be put into place to contain suspended contaminants depending on the type of dredging.

Residuals: Post-removal sampling and surveying to determine whether sediment removal objectives were met, if not; re-dredging if greater than 10 ppm or backfilling if less than 10 ppm.

An engineered cap will be used for areas where dredging could damage riverbank (estimated 450 acres).

Sand covers where the maximum PCB level is less than 2 ppm and where the contaminated sediment layer is no thicker than 6 inches.

RAOs/project objectives achieved? Work is in progress on these sites.

A.16.6 References

U.S. EPA. Record of Decision Amendment Operable Unit 2 (Deposit DD), Operable Unit 3, Operable Unit 4, and Operable Unit 5 (River Mouth). June 2007. http://www.epa.gov/superfund/sites/rods/fulltext/a2007050002100.pdf.

U.S. EPA. First Five-Year Review Report for Fox River NRDA/PCB Releases Site. July 2009. http://www.epa.gov/superfund/sites/fiveyear/f2009050002959.pdf .

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.smwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.17 Gill Creek, NY

A.17.1 Summary

Environment:	Freshwater
Scale:	Field
Contaminants of Concern:	VOCs, Mercury, PCBs: 11,000 ppm
Final Remedy:	Hydraulic and mechanical dredging using cofferdams and sandbags for to dewatering. Sediment was stabilized with fly ash and kiln dust then transported to an RCRA and TSCA permitted landfill. 230 yd^3 was deemed hazardous and was incinerated.

A.17.2 Site Description

The site is owned by E.I. DuPont and consists of a 250-foot sector of creek near its confluence with the Niagara River.

Year: 1992

Target Volume:

- Area 1: 3,400 yd^3
- Area 2: 160 yd^3
- Area 3: 40 yd^3

Actual Volume Removed: 8,020 yd^3

A.17.3 Remedial Objectives

- BHCs: 0.045 ppm
- PAHs: 22 ppm
- Mercury: 0.2 ppm

A.17.4 Remedial Approach

Only sites OU 3–OU 5 were dredged. A compacted clay liner was installed to prevent groundwater seepage into creek.

A.17.5 Monitoring

Contaminant concentrations were significantly lower after dredging. No capping was required for this site. Post-remediation monitoring was planned for 5 years, consisting of sediment and water sampling.

RAOs/project objectives achieved? Based on confirmatory sampling, cleanup levels were met. A long term monitoring plan is in place to assure the protection of human health and the environment.

A.17.6 References

U.S. EPA. Realizing Remediation II An Upland Summary of Contaminated Sediment Remediation Activities at Great Lakes. July 2000. http://www.epa.gov-/glnpo/sediment/realizing2/RR2report.PDF.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.18 Port of Portland, OR

A.18.1 Contacts

USEPA Region 10

A.18.2 Summary

Environment:	Lake remnant
Scale:	Full
Contaminants of Concern:	Lead and dioxin
Source Control Achieved Prior to Remedy Selection?	No
Final Remedy:	Dredging and dewatering of sediments followed by placement in on-site containment facility

A.18.3 Site Description

A lead battery recycler and pesticide/herbicide manufacturer were located adjacent to Doane Lake. Over the years, waste materials were disposed of in Doane Lake resulting in the lake being divided into two remnants—East Doane Lake and West Doane Lake. Other operations in the vicinity of Doane Lake include acetylene production and auto fluff disposal. The site is located adjacent to the Willamette River (RM 7) in Portland Harbor. The primary sources of contamination at this site are waste discharges from the battery recycler and pesticide/herbicide manufacturer.

A secondary lead smelting facility was constructed on the current Gould property and began operations in 1949 under the ownership of Morris P. Kirk and Sons. Facility operations consisted of lead-acid battery recycling, lead smelting and refining, zinc alloying and casting, cable sweating, and lead oxide production. Discarded battery casings and other waste materials from the operations were disposed on the Gould property and adjacent properties. NL Industries purchased the property in 1971 and sold it to Gould in 1979. The facility was closed in 1981, and by the summer of 1982, most of the structures, facilities, and equipment had been removed. The Rhone-Poulenc site, a site being managed by the State of Oregon cleanup program, is adjacent to the Gould Site. East Doane Lake received waste materials from both facilities resulting in lake sediments contaminated with polychlorinated dibenzo-p-dioxins and furans (PCDD/F).

The original remedy for the site called for excavation and treatment of lead contaminated material. Because of technical concerns, USEPA issued an amended Record of Decision (AROD) in 1997. The AROD called for consolidating the stockpiled contaminated soil, debris, and stabilized blocks within the area of contamination, and placing them in an on-site containment facility (OCF) that includes a leachate collection system. In addition, the AROD called for dredging of East Doane Lake sediments, filling the lake remnant with clean fill, dewatering of the excavated sediments, and placement in the OCF.

The Gould Superfund Site is located in the City of Portland, Oregon between NW St. Helen's Road and NW Front Avenue in a heavily industrialized area northwest of downtown Portland known as the Doane Lake area. The Site includes a 9.2 acre property currently owned by Gould Inc. that was the location of the former secondary lead smelter and battery recycle facility and areas outside the property boundary where battery casings and other residues from operations on the Gould property were placed. The Gould Site is adjacent to the former location of the Rhone-Poulenc Ag Company (Rhone-Poulenc) facility.

A.18.4 Remedial Objectives

Two primary remedial objectives relevant to the sediment portion of the remedy were established:

1. Direct contact exposures: Prevent direct contact exposures to battery casings, waste material, and contaminated soils; and
2. Groundwater: Minimize migration of contamination from waste materials to groundwater.

A.18.5 Remedial Approach

Final selected remedy: Hydraulic dredging, sediment dewatering and disposal in an on-site containment facility (OCF).

Dredging, mechanical dewatering, and stockpiling an estimated 8700 yd^3 of contaminated EDLR sediment and debris was completed in November 1999. Dewatering was accomplished through the use of filter presses. Contaminated sediments included lead contaminated sediments addressed by the Gould remedy and PCDD/F and herbicide contaminated sediments addressed by a State of Oregon Removal action performed in conjunction with the USEPA Gould Remedy. In addition, 55 compressed gas cylinders that were buried in the east portion of EDLR were recovered, over packed, and transported to an off-site facility for treatment and disposal.

Contaminated sediments were removed to remove a potential source of groundwater contamination. The lake remnant was backfilled with clean fill to prevent exposure to contaminated material and to facilitate site redevelopment. The East Doane Lake remnant was determined to be an aquatic resource of very limited natural function. East Doane Lake had been used for industrial waste discharge from the lead smelting facility formerly located on the Gould property, an acetylene gas production facility formerly located on the Schnitzer site, and the herbicide production facility formerly located on the Rhone-Poulenc site. Remediation of the contaminated portions of the Gould Site Soils operable Unit was expected to reduce or eliminate exposure to contaminated sediments and possible uptake of contaminants from the sediments into the aquatic environment.

A.18.6 Monitoring

Lead levels in groundwater samples collected from wells located directly downgradient from the site have been below 0.015mg/l, the current action level for lead established by the Safe Drinking Water Act (SDWA), for the past five years, and most of the results have been non-detect for lead.

RAOs/project objectives achieved? Through removal of contaminated sediments and filling of the lake remnant, the project objectives were achieved. The project successfully removed lead and PCDD/F contaminated sediments from the lake remnant eliminating exposure to contaminated sediments and eliminating a source of groundwater contamination.

A.18.7 References

USEPA, Region 10: The Pacific Northwest, Gould, Inc. http://yosemite.epa.gov/R10/cleanup.nsf/7d19cd587dff1eee8825685f007d56b7/90a98d27ff0206af8825651a00598ed2!OpenDocu

A.19 Grand Calumet, IN, 2003

A.19.1 Summary

Environment:	Freshwater
Scale:	Full
Contaminants of Concern:	PAHs, PCBs: average of 17 ppm (max of 350 ppm) prior to dredging, metals, cyanide
Final Remedy:	Sheet piling used to stabilize banks. Cofferdams were used to contain dredging areas over 50 ppm. Sediment deposited at an on-site 36-acre CAMU.

A.19.2 Site Description

Year: 2003

Water depth: 0–4 ft

Target volume: 750,000 yd^3

Actual volume removed: 788,000 yd^3

Contaminated sediment area: Five-mile stretch of river

A.19.3 Remedial Objectives

- Remove nonnative sediment.
- PCBs: 50 ppm in certain transects

Dredge depth: 0–20 ft

A.19.4 Remedial Approach

The remedial approach consisted of dredging of nonnative sediment. Sediment was disposed of at an on-site landfill.

PCB levels above 50 ppm goal prompted a second remedial event.

A.19.5 Monitoring

A floating debris boom, oil boom, and turbidity curtain were maintained 2,000–3,000 ft downstream of dredge to monitor resuspension.

RAOs/project objectives achieved? Immediate goals were met, but samples showed increases as time passed. In 2007, USEPA requested further dredging in areas where samples indicated PCB concentrations greater than 50 ppm.

A.19.6 References

U.S. Steel Gary Works. Grand Calumet River Sediment Remediation Project. Grand Calumet River Sediment Remediation Project Newsletter, GCR Issue 2. May 2003. http://www.c-su.edu/cerc/documents/GrandCalumetRiverDredgingPlanMap.pdf.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.20 Grand Calumet, IN 2007

A.20.1 Summary

Environment:	Freshwater
Scale:	Full
Contaminants of Concern:	PCBs: excessive amount of non-native sediment after 2003 dredging (≥50 ppm)
Final Remedy:	Dredging non-native sediment. Sediment was disposed at an on-site landfill.

A.20.2 Site Description

Year: 2007

Water Depth: 0–4 ft

Target Volume: 24,000 yd^3

Actual Volume Removed: 38,000 yd^3

Contaminated sediment area: 6,300 ft stretch of river

A.20.3 Remedial Objectives

- Remove nonnative sediment.
- Address PCBs over 50 ppm in areas that still remain from 2003 event.

A.20.4 Remedial Approach

The original site work was completed 2003. PCB levels above 50 ppm goal prompted this second event. Follow-up work consisted of dredging of nonnative sediment. Sediment was disposed of at an on-site landfill.

A.20.5 Monitoring

Sediment sampling done after dredging confirms that concentrations were below 50 ppm PCB.

RAOs/project objectives achieved? After the second dredging event, samples confirmed that all levels were below 50 ppm, and the goal was met.

A.20.6 References

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.21 Grasse River, Massena, NY

A.21.1 Summary

Environment:	River
Scale:	Pilot
Contaminants of Concern:	PCBs

A.21.2 Site Description

The site is located on the Grasse River in Massena, NY. Alcoa, Inc. began a pilot study in 2001 to evaluate subaqueous capping as a potential remedial alternative for addressing polychlorinated biphenyls (PCBs) in sediment and biota of the lower seven miles of the Grasse River near Massena, NY. The pilot study examined various cap materials and application techniques in a seven-acre study area. Data collected over the following year demonstrated that the cap had remained intact and relatively unchanged and was functioning as designed. Spring 2003 monitoring results, however, indicated a loss of cap material and underlying sediment in the study area. Investigations found that these changes were caused by a severe ice jam that formed directly over the cap.

CSM summary: Modeling indicated that scour of the cap material, underlying sediment, and sediment outside the study area was caused by the turbulence and high velocity of water flow below the ice. The turbulence and high water velocity resulted from an increase in water stage upstream of the ice jam, a reduced cross section below the jam, and the roughness of the ice jam. Sonar imagery and underwater videography supported the finding that scour resulted from hydraulic forces below the toe of the ice jam rather than physical contact between the ice and sediment.

The extent and magnitude of sediment disturbance caused by the ice scour event was characterized by examining changes in sediment elevation and type relative to pre-ice-jam conditions. Comparisons indicated that scour ranged in depth from 0.4 to 5.0 ft and occurred in about 15% of the river bottom in the uppermost 1.8 miles of the Lower Grasse River. Part of this area included the cap demonstration area, and some of the deepest erosion occurred in an area that contained a 24-inch thick sand/topsoil cap covering approximately 1.2 acres. Much of the material that eroded in this area was deposited immediately downstream, where a 4.6-foot increase in sediment elevation was noted.

Redistribution of sediments and PCBs during the 2003 ice jam and scour did not significantly affect average PCB concentrations in sediment, water, and fish, suggesting that potential PCB exposure in the river did not change significantly. Surface sediment PCB concentrations in the scour area, however, were higher and more variable than before capping, averaging 13 ppm instead of 8 ppm. This increase is attributed to exposure of deeper sediments typically containing higher PCB concentrations. Surface sediment PCB concentrations decreased in areas subject to deposition, as evidenced by a three-fold reduction immediately downstream of the study area.

A review of historical records and physical evidence such as tree scarring indicated that possibly six ice jam events have occurred in the Lower Grasse River over the past 40 years. Analysis of high-resolution and stratigraphic cores suggested that ice jam-related scouring occurred in the Lower Grasse River four times over the same period or about once each decade. Results of this and other investigative work to date indicate that ice jams, and resulting scour associated with severe ice jams, are limited to the upper 1.8 miles of the Lower Grasse River and current proposed remedial plans have included additional armoring of a cap in this area.

A.21.3 References

Beckingham, B. & U. Ghosh, 2011, Field Reduction of PCB Bioavailability with Activated Carbon Amendment to River Sediments, *ES&T*, 45(24): 10567-74.

Record of Decision, Grasse River Superfund Site (a.k.a. Alcoa Aggregation Site). http://www.srmtenv.org/web_docs/Superfund/alcoawest/2013/2013-April-Grasse-ROD-Full.pdf.

A.22 Grasse River, NY (hotspot removal)

A.22.1 Summary

Environment:	Marine
Scale:	Full
Contaminants of Concern:	PCBs: 12–11,000 ppm prior to dredging
Final Remedy:	Hot spots were removed using hydraulic dredging assisted by a diver with a vacuum dredge in the shallows. Dredge material was deposited in an existing on-site TSCA/RCRA landfill.

A.22.2 Site Description

Fresh water: 10–15 ft deep

Year: 1995

Contaminated sediment area of one-acre near shore.

A.22.3 Remedial Objectives

- Remove as much sediment as practical within an area bounded by a 10 ppm isopleths that would result in a 25% reduction in PCB mass.
- Dredge depth: 0-2 ft

A.22.4 Remedial Approach

- SWAC was used.
- A hydraulic auger dredge was used along with diver assisted vacuum dredging in shallows. Floating oil booms and three silt curtains (an outer, inner secondary and one for near shore boulder zone) were used.
- Silt curtains were hung to contain suspended sediment but sampling outside the curtains showed increases in concentrations.
- Surface sediment residuals PCBs ranged from 1.1–260 ppm after dredging.
- An undetermined amount of rocky debris on site made dredging difficult.

A.22.5 Monitoring

Resuspension occurred during the dredging operation. No details on resuspension controls for this site. Most activities were performed at extreme low tide. Sheet piling was used to withhold water from the dredging areas.

RAOs/project objectives achieved? Fish studies performed postdredging showed that fish PCB levels were 20–50 times higher immediately after the dredge action. These levels reduced to pre-removal levels three years after removal event. Sediment sampling following removal indicated levels decreased from 518 to 75 ppm in the top foot and from 1,109 to 75 ppm in all depths. 85% of projected mass was removed.

A.22.6 References

Alcoa, U.S. EPA. Superfund Program Update for the Grasse River Study Area. Jun 2004. http://www.thegrasseriver.com/pdf/Final_June_2004_Newsletter.pdf.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.23 Grasse River, NY

A.23.1 Summary

Environment:	Marine
Scale:	Pilot
Contaminants of Concern:	PCBs: average concentration 11 ppm
Final Remedy:	Hydraulic cutterhead dredge

A.23.2 Site Description

Freshwater, 10–15 feet deep.

Year: 2005

A.23.3 Remedial Objectives

The remedial objective is to bring additional information to the decision-making process in key areas of uncertainty and to make progress towards cleanup of the river.

A.23.4 Remedial Approach

This event was a pilot study for different capping materials and their efficiencies. A hydraulic cutterhead dredge was used. Dredged material was dewatered and disposed in an existing on-site TSCA/RCRA landfill. Water was treated and deposited back into the river. Some Geotube dewatering was used.

Only 40% of the planned area was dredged. The river bottom was rocky and uneven, resulting in slowed progress and multiple equipment failures.

A.23.5 Monitoring

RAOs/project objectives achieved? Samples outside silt curtains showed high concentrations of contaminants. Dredged areas were backfilled with different materials (sand, topsoil, and armor stone) at different locations to determine best one. Once backfilled, levels were 95% lower after dredging.

A.23.6 References

Alcoa, U.S. EPA. Superfund Program Update for the Grasse River Study Area. Jun 2004. http://www.thegrasseriver.com/pdf/Final_June_2004_Newsletter.pdf.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.24 Grubers Grove Bay; Prairie Du Sac, WI

A.24.1 Contacts

Regulatory Contact(s): Wisconsin, DNR

A.24.2 Summary

Environment:	Lake remnant
Scale:	Full
Contaminants of Concern:	Mercury, methylmercury, lead, copper, and zinc
Source Control Achieved Prior to Remedy Selection?	No
Final Remedy:	Dredging and dewatering of sediments using Geotubes followed by placement on site and capping with a soil cover

A.24.3 Site Description

Grubers Grove Bay is located in Lake Wisconsin, an impoundment of the Wisconsin River created by the Wisconsin Power & Light dam constructed in 1915 at Prairie du Sac. The primary source of contamination at the site is contaminated wastewater discharge from the Badger Army Ammunition Plant (BAAP) in Sauk County. Discharges took place between 1942 and 1976. Gruber's Grove Bay, due to its elevated mercury levels, was added to USEPA's impaired waters (303d) list in 2000.

The Badger Army Ammunition Plant (BAAP) operated between 1942 and 1976. The BAAP was built and operated by the U.S. government to produce various formulations of nitrocellulose-based propellants including nitroglycerine. Nitric and sulfuric acid were also produced as intermediate materials used in manufacturing those propellants. At the time of its construction, it was one of the largest ammunition plants in the world. The operation of the BAAP caused extensive contamination of soils, surface water sediment, and groundwater. Both production and waste-disposal practices at BAAP account for contamination at this site.

A.24.4 Remedial Objectives

The primary remedial objective relevant to the sediment portion of the remedy was removal of contamination to promote recovery of the benthic community.

A.24.5 Remedial Approach

Final selected remedy: Hydraulic dredging, sediment dewatering, and disposal in an on-site containment facility (OCF).

Two sediment cleanups were performed. The initial cleanup was performed in 2001 and resulted in the removal and dewatering of approximately 90,000 yd^3 of contaminated sediment. Subsequent sampling, however, found that mercury and other metals were still present over a wide area of the bay's sediment at levels above the cleanup goal. A second cleanup was completed in 2006. Approximately 60,000 $yd^3$of sediment harboring mercury, methyl mercury, lead, and copper were dredged over a 17 acre area. The sediment was pumped with water from the bay into 42 geomembrane tubes placed on a plastic liner on BAAP land where it was covered with a final soil cap. More than 66 million gallons of the dredged water was collected as it drained to sediment collection tubes and was distributed as irrigation water to three areas on BAAP property.

During dredging operations, a silt curtain was placed across the mouth of the bay to prevent contaminant releases to Lake Wisconsin. Dredging depth was verified using GPS in conjunction with an echo sounder. Problems affecting the dredging operation included heavy precipitation, tears in Geotubes, and the presence of debris within the sediment bed.

Sediment slurry was pumped from the dredge to a series of Geotubes located on the BAAP plant site. A polymer was added to the dredge slurry to increase flocculent growth and retention of fine particles in the water. Water from the Geotubes was discharged to a storage lagoon for spray irrigation. Mercury levels in the effluent were generally non-detect or below the discharge permit level.

The cleanup target for mercury was 0.36 milligrams per kilogram (mg/kg), the background standard for mercury in the bay, in the top 6 inches of sediment. Also removed from the bottom were lead, copper, and zinc, metals bound together in the sediment particles.

It is estimated that the two dredging operations removed 500 pounds of mercury, 12,000 pounds of copper, 16,000 pounds of zinc, and 36,000 pounds of lead from the bay.

Approximately 2 acres of habitat restoration was completed following implementation of the dredging operation.

A.24.6 Monitoring

WDNR performed testing at the site and found eight of the ten sediment samples exceeded the cleanup goal of 0.36 ppm. WDNR test results for mercury ranged from 0.24 to more than 9 ppm.

RAOs/project objectives achieved? It is unclear if the project objectives were achieved.

A.24.7 References

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.25 Hackensack River, NJ

A.25.1 Contact

Regulatory Contact: U.S. District Court of New Jersey

A.25.2 Summary

Environment:	Estuary
Scale:	Full
Contaminants of Concern:	Chromium
Source Control Achieved Prior to Remedy Selection?	Yes
Final Remedy:	Dredging (0.5 acres), capping (30 acres), MNR (53 acres)
Expected Recovery Time:	Recovery achieved
MNR viewed as a success?	Not yet determined

A.25.3 Site Description

Study Area 7 is a 34-acre site bordering the Hackensack River, near the confluence with Newark Bay in Jersey City (Hudson County), New Jersey. The primary source of contaminants at this site is chromium ore processing residue used as fill in the Study Area 7 waterfront.

This area has been used for industrial and commercial purposes for over a hundred years. The operation of a sodium dichromium manufacturing facility from 1905-1954 (Mutual Chemical Company of America) led to chromium contamination. Chromium ore processing residue were used as fill material in Study Area 7 (at that time a common practice). Approximately 1 million yd^3 of this material were used, leading to elevated chromium concentrations in Hackensack River sediment through historical groundwater seepage and surface runoff.

CSM summary: The primary natural recovery process in Study Area 7 is chemical transformation of hexavalent chromium, Cr(VI), to trivalent chromium, Cr(III). Cr(VI) rapidly transforms into Cr (III) under reducing or mildly oxidizing conditions. Cr(III) is much less bioavailable and toxic than CR(VI). Cr(VI) rarely forms in nature due to kinetic constraints, although it is thermodynamically favored under aerobic conditions.

In Study Area 7, Cr(VI) is transformed almost immediately to Cr(III) upon contact with sediments, which were characterized as reducing. A secondary natural recovery process is the physical isolation of buried sediments. By enhancing the primary natural recovery process this further supports the requirement to remedy sediments containing greater than 370 mg/kg total chromium.

Lines of evidence supporting chemical transformation, reduction in bioavailability, and mobility (very low bioavailability of chromium in sediments) included indicators of redox conditions in surface sediment, Cr(VI) detection in pore water samples, sediment resuspension and oxidation test, Cr(VI) detection in subsurface groundwater, biota tissue analyses, and toxicity tests.

Lines of evidence supporting physical isolation processes and sediment stability included sediment trap analysis, radiological tracer measurements, sediment shear strength studies, hydrodynamic modeling, and an analysis of vertical chromium profiles in sediment cores.

A.25.4 Remedial Objectives

The primary concerns are ecological risks from chromium in sediment.

RAOs/project objectives: A remedy must be applied to all sediments, regardless of depth, that exceed the New Jersey Department of Environmental Protection's effects range-median sediment quality goals of 370 mg/kg, as required by the consent decree governing the site.

A.25.5 Remedial Approach

Final selected remedy: Dredging (0.5 acres), capping (30 acres), and MNR (53 acres)

The recommended remedy alternative involved source control, capping of sediments with total chromium concentrations greater than 2,000 mg/kg, and MNR for the remaining areas. The negotiated remedy involved dredging 2,000 yd^3 over 0.5 acres; a 14-acre, 12-inch cap; a 15-acre, 6 inch cap; and MNR for 20 acres whose subsurface concentrations exceeded 370 mg/kg. Capping targeted areas where surface sediments total chromium concentrations were greater than 370 mg/kg, while MNR targeted areas where surface sediment concentrations were less than 370 mg/kg but subsurface sediment concentrations exceeded 370 mg/kg.

This remedy was selected because it was determined that chromium was present in a net-depositional area in a form that was geochemically stable and nonbioavailable. In addition, only moderate resuspension was expected during high-energy events. MNR was selected after a detailed comparative risk analysis of several alternatives (no action, three capping remedies, and two dredging remedies). The risk analysis considered the following factors:

- worker risks associated with construction and transportation
- community quality of like impairments (noise, odor, diesel emissions, traffic congestion)
- short-term benthic habitat loss and recovery times
- risk reduction associated with changes in surface sediment concentrations of chromium
- long-term recontamination potential

The risk analysis also took into account both the short-term risk of implementing each remedy as well as the anticipated long-term risk reduction. The analysis showed that MNR provides comparable risk reduction to other remedies. Considering cost as well, it showed that the increasing costs associated with capping dredging did not proportionally decrease risk. Therefore, MNR provided comparable or greater risk reduction to other alternatives while also minimizing cost and the impact of removing the sediment.

The primary lines of evidence used to investigate MNR included lines of evidence used to support chemical transformation (reduction in bioavailability and mobility) such as indicators of redox conditions, pore water analyses, sediment resuspension and oxidation tests, biota tissue analyses, and toxicity tests. Lines of evidence supporting physical isolation includes sediment trap analysis, radio-isotope analysis, hydrodynamic modeling, sedflume shear strength studies, sediment coring, and vertical chromium profiling.

A.25.6 Monitoring

Monitoring covers sediment stability, physical isolation of chromium concentrations, geochemical stability of Cr(III), and sediment cap integrity. Tide gauges gather data to model shear forces, velocities, and hydrodynamic conditions to determine maximum velocities where MNR performs acceptably. Bathymetric and SPI camera data are used to calculate erosion and changes in sediment bed elevation. Finally, pre-water samples help to determine the risk reduction and monitor the geochemical stability of Cr (III) in surface sediments.

The area will be monitored for 15 years after objectives have been reached, assuming that they are maintained for those 15 years. Or, monitoring will continue through at least two high-energy events.

Expected recovery time: Recovery has been achieved.

RAOs/project objectives achieved?: Recovery has been achieved; current monitoring focuses on verifying performance.

Overall it is not yet determined if MNR is successful. MNR will be considered successful if five years of routine monitoring and 15 years of severe event monitoring show acceptable bed elevations through bathymetric surveys.

A.26 Niagara Falls, NY

A.26.1 Summary

Environment:	River
Scale:	Full
Contaminants of Concern:	Benzene, chlorobenzene, chlorophenols, and hexachlorocyclohexane, Hg, heavy metals
Source Control Achieved Prior to Remedy Selection?	No
Final Remedy:	MNR, capping, and dredging
Expected Recovery Time:	NA; contamination left in place

A.26.2 Site Description

The Hooker 102nd Street Landfill consists of two parcels totaling 22.1 acres. The site is located on Buffalo Avenue in Niagara Falls, New York. It borders the Niagara River and lies less than ¼ mile south of the Love Canal Superfund site. A portion of the filled area of the site is an extension of the original Love Canal excavation. The site is bounded to the south by a shallow embayment of the Niagara River. To the west of the site is Griffon Park, which was formerly used as a landfill for municipal waste by the city. The 100th Street storm sewer crossed the site and discharged to the Niagara River. The primary source of contamination at this site was improper disposal of at least 159,000 tons of various chemical wastes.

Occidental Chemical Corporation, formerly Hooker Chemical and Plastics Corporation, owns 15.6 acres, and the remaining 6.5 acres are owned by Olin Chemical Corporation. The larger portion of the landfill was operated from 1943 until 1971 and the smaller portion from 1948 to 1970. During that time at least 159,000 tons of waste, in both liquid and solid form, was deposited into the landfill. The waste included mixed organic solvents, organic and inorganic phosphates, brine sludge, fly ash, electrochemical cell parts and related equipment, hexachlorocyclohexane process cake, lindane, benzene, chlorobenzene, and chlorophenols.

In 1972, the site was capped and fenced on three sides, and a bulkhead along the Niagara River was installed. In 1979, a complaint, pursuant to the Resource Conservation and Recovery Act, the Clean Water Act, and the Rivers and Harbors Act of 1899, was filed against the two companies. In 1983, the site was added to the National Priorities List.

The remedial investigation began in 1984 was completed in 1990. The remedy was completed in 1999, and the site was deleted from the NPL in 2004.

A.26.3 Remedial Objectives

Dredging activities associated with the removal of sediments in the river can have short term negative impacts on the Niagara River due to the possible release of contaminated sediments. Berms will be constructed beyond the area of contamination to retain any loosened sediments, preventing their transport into the river from the embayment. The construction of the berms could temporarily increase sediment loads to the river.

RAO(s)/project objectives for this site include:

- Contain the NAPL plume with the slurry wall.
- Consolidate contaminated sediment beneath the cap on site.
- Comply with ARARS.

A.26.4 Remedial Approach

Final selected remedy: MNR, capping, and dredging

In September 1990, the USEPA selected the site remedy. The remedy was modified in a ROD amendment in 1996. The final remedy includes:

- Dredging the Niagara River sediments to the "clean line" with respect to site related contamination. These sediments, after dewatering, were not incinerated as originally specified, but were consolidated on the landfill. Nonaqueous phase leachate (NAPL) found within these sediments was extracted and incinerated at an off-site facility. Dredging was completed in November 1996.
- A synthetic-lined cap, completed in November 1997, was constructed in accordance with federal and state standards was installed over the landfill and perimeter soils.
- Off-site soils above cleanup thresholds were consolidated beneath the cap.
- A slurry wall surrounding the site's perimeter was constructed and keyed into the underlying clay/till geologic formation. The intent was to contain NAPL. The slurry wall was completed in May 1997.
- Groundwater will be recovered using an interception drain installed at the seasonal low water table in the fill materials. Recovered groundwater will be treated. The main purpose of the groundwater recovery is to maintain an inward gradient across the slurry wall. The groundwater system was started in 1999.
- In 2005, there were 18,153 gallons of NAPL beneath the site which will be recovered using eight dedicated recovery wells and incinerated at an off-site facility. In 2006, 12,151 gallons of NAPL was recovered and sent off site to be incinerated.
- The existing storm sewer will be abandoned in place and covered by the cap.
- A 6-foot chain link fence will be installed around the perimeter of the cap in order to restrict access to the site.

- Institutional controls in the form of deed restrictions, precluding the extraction of groundwater other than required for implementation, and operation and maintenance of the remedy and any excavation, construction, or other activities that could interfere with the integrity of the landfill cap or other engineering controls in place at the site were filed in January 2000.

The remedy was selected because the major human exposure pathways included the ingestion of fish from the embayment in the Niagara River, exposure of individuals while swimming in the embayment and the little Niagara River, the ingestion of drinking water from the Niagara River as it is withdrawn at the Niagara Falls drinking water treatment plant, and dermal contact with, ingestion of, and inhalation of dust from off-site contaminated soils. The selected remedy of consolidation, capping, and containment effectively eliminates each of these pathways leading to human exposure. The ingestion of fish pathway will be eliminated since no contaminants can leach from the landfill area due to the existence of the slurry wall keyed into the confining layer, the capping of the site, and the maintenance of an inward gradient across the slurry wall. The pathways involving swimming in the river and drinking water from the river will be eliminated since the entry of contaminants into the river will be eliminated. Exposure to any dust from contaminated off-site soils will be avoided since all contaminated off-site soils will be consolidated on site beneath the cap.

A.26.5 Monitoring

Water levels inside the slurry wall and immediately outside are monitored to determine whether an inward gradient is maintained. Perimeter wells outside the slurry wall are sampled to monitor the quality of groundwater leaving the site. Surface water quality was not being monitored at the time of the second Five Year Review but was recommended.

Costs: Estimated annual monitoring costs were $100,000 in the Second Five Year Review.

RAOs/project objectives achieved? According to the Second Five Year Review, it was not possible to determine whether an inward gradient inside the slurry wall was being maintained and site contaminants of concern were consistently detected in downgradient perimeter wells above the regulatory criteria.

A.26.6 References

USEPA, Hooker-102nd Street NPL Listing. http://www.epa.gov-/Region2/superfund/npl/0201706c.pdf.

A.27 Housatonic River, MA

A.27.1 Summary

Environment:	Freshwater
Scale:	Full
Contaminants of Concern:	PCBs, NAPLs
Final Remedy:	Cofferdam/sheet piling was in place to dewater contaminated sediment. Material was excavated and disposed of at an on-site facility.

A.27.2 Site Description

The Housatonic River in Pittsfield, MA, its sediment, and its associated floodplain are contaminated with PCBs and other contaminants. The USEPA performed a 1½ Mile Reach Removal Action using two excavation techniques costing a total of $84,000,000.

A.27.3 Remedial Approach

Excavation was chosen because the river was too shallow for conventional dredging and had a sandy, rocky bottom. Further, there was free-phase NAPL that could be better controlled and isolated with dry dredging.

The first technique used was a 1,400 ft length sheet pile coffer dam technique which consisted of using sheet pile to construct individual sheet pile installed along the centerline of the riverbed. Then, upstream and downstream sheet pile cut-off walls were installed branching off the centerline sheet pile wall and extending up the riverbank. The river flow was thus diverted around the sheet pile cell. The cell was then dewatered and the sediment and riverbank soil was removed. The cell was then backfilled with clean fill and riprap to the design grade. Next, the two cut-off walls were removed and re-installed on the opposite side of the river creating the next cell to be remediated and restored. Remediation activities proceeded downstream with activities alternating from one side of the river to the other. Standard excavating equipment was used to complete the sediment and soil removal and backfilling. A typical sheet pile cell was approximately 300 ft long and approximately 30 ft wide. Water was removed from each sheet pile coffer dam system down to 6 inches of water above the sediments and directly discharged into the river. The remaining water was subjected to water treatment and then discharged back into the river. Sediments consisted of mostly sand and gravel. Removed sediments were stockpiled within the river cell for gravity dewatering.

The second technique, excavation, involved a gravity-fed bypass system. The bypass system consisted of a temporary river diversion dam installed approximately 1,400 ft downstream from the Lyman Street Bridge. The gravity-fed bypass technique was used in this area because shallow bedrock prevented the use of the sheet pile cofferdam system. The bypass system diverted the river flow into two 54-inch movable high density polyethylene pipes. The pipes were placed along one side of the river channel and the riverbed sediment and soil on the other side were removed and backfilled. The sediment and soil removal and backfilling was accomplished using standard excavation equipment. Once the backfilling was complete, the pipes were moved to the remediated side of the river and the process was repeated. Additional sections of pipe were added to the two 54-inch pipes extending the system as the removal and restoration progressed downstream. The gravity bypass system was used to remediate and restore approximately 3,400 ft of the river channel to a location 400 ft downstream of the Dawes Avenue Bridge.

Dry excavation here was more effective in controlling sediment resuspension than conventional dredging would have been. Limited resuspension occurred during sheet pile installation. In total, approximately 91,700 yd^3 of contaminated sediment and riverbank material was removed and disposed of as part of the 1½ Mile Reach Removal Action. Approximately 7,000 yd^3 of this material was impacted by NAPL. Approximately 50,750 yd^3 of the contaminated material was disposed of at GE's on-plant consolidation areas and the remainder of the contaminated material, including all of the NAPL-impacted material, was disposed of at licensed off-site disposal facilities. The sediment remediation action met the cleanup goals.

A.27.4 Additional Areas

Year: 2002

Water Depth: 0–8 feet

Target Volume:

Hotspot: 2,800 yd^3

Half mile: 12,100 yd^3

Actual Volume Removed:

Hotspot: 7,000 yd^3

Half mile: 18,138 yd^3

A.27.5 Remedial Objectives for Additional Areas

Hot spot: Area average of > 5 ft depth: 1 ppm, < 5 ft depth: 10 ppm.

Half mile: 1–3 ft depth: 15 ppm

Contaminated sediment area: 0.5 mile segment

A.27.6 Remedial Approach

Hotspot in Silver Lake. First half mile of the river was remediated as well.

An isolation cap was installed on areas not dredged. This cap consisted of a geotextile layer, and isolation sand layer, another layer of geotextile and geogrid and stone armor layer.

A.27.7 Monitoring

Sheet piling was in place to contain contaminated sediment area and to dewater it for dry excavation. No suspension measures needed for this site because both areas used dry excavation. The project was slowed by periodic presence of NAPLs.

Dredged areas were backfilled and seeded/ replanted.

A.27.8 References

USEPA, EPA Cleanups: GE-Pittsfield/Housatonic River Site Housatonic River ½ Mile Removal-Reports. http://www.epa.gov/region1/ge/thesite/halfmile-reports.html.

USEPA, EPA Cleanups: GE-Pittsfield/Housatonic River Site Housatonic River 1½ Mile Removal-Reports. http://www.epa.gov/region1/ge/thesite/1andhalfmile-reports.html.

USEPA, EPA Cleanups: GE-Pittsfield/Housatonic River Site Silver Lake-Reports. http://www.epa.gov/region1/ge/thesite/silverlake-reports.html.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.28 Hudson River, NY

A.28.1 Contact:

EPRI Project Manager- Jeffrey A. Clock (jclock@epri.com)

A.28.2 Site Description

At the EPRI Reactive Capping Demonstration Project on the Hudson River in New York, sediments were located at water depths exceeding 50 ft, with tidal river currents often exceeding 4 fps. The sediments were located in a tidal, freshwater estuary. The contaminants of concern were coal tar NAPLs, and PAHs.

CSM summary: The site was adjacent to a former manufactured gas plant at which coal gas manufacturing byproducts were discharged into the river and which subsequently settled in sediments. NAPLs are present in surface and deeper sediments and can be visible at the sediment/water interface and as surface sheens.

A.28.3 Remedial Objectives

The objective of this demonstration project was to demonstrate the feasibility of using reactive capping materials over deep water sediments to sequester NAPLs. This was a pilot scale, field demonstration of the technology.

A.28.4 Remedial Approach

Laboratory studies using coal tar NAPLs were used to identify organoclay materials with the greatest absorptive capacity. CETCO reactive core mats attached to rock-filled Tensar Triton Marine Mattresses were used to place reactive material on sediment surfaces. Sand and sand/bulk organoclay mattress systems were also deployed. Total sediment surface area covered was 10,000 ft^2, one-third of which was covered with each of the three capping systems.

Mattress systems were deployed and monitored for 18 months, after which they were removed and tested.

A.28.5 Monitoring

After deployment, the mattress systems were visually examined for physical integrity by divers at approximately four-month intervals. Mattresses retained original conditions for the duration of the project.

Sediment traps were deployed and observed. Two to twelve inches of sediments were redeposited over the mattress systems over the 18 month test period.

NAPL/PAH-sensitive materials (Tyvek and DART samplers) and SPME samplers were tested at each monitoring interval. No NAPL breakthrough was observed.

After removal of the mattress systems, samples of the reactive core mats were examined in the laboratory. Results indicated that, after 18 months of use, absorptive capacity and permeability of the organoclay in the mats was comparable to virgin material.

A.28.6 Costs

The total project cost was approximately $1.8 million, including testing and monitoring, assembly, deployment, and removal of mattress systems.

Reactive core mat/marine mattress systems (materials plus delivery to the site) cost \$7 per ft^2 and assembly and Installation costs were \$70 per ft^2.

A.28.7 Advantages and Limitations

Regulatory – even with support of the State DEC, permitting was challenging in that state and federal permits were required for this research project. Agencies involved included Army Corps of Engineers, US Fish and Wildlife Service, NYS DEC, NYS Office of Parks and Historic Preservation, NYS Dept. of State.

Technical – deployment of RCM at depth and in an area of high currents.

RCM was shown to be effective. Samples taken after 18 months of use show that absorption and permeability of the material was comparable to new material specifications. In addition RCM was shown to be more effective than sand or sand and bulk organoclay.

The mattress systems were subjected to numerous lifts during deployment and removal. Several mattress lifting systems failed while being removed from the test site. While most projects would not ordinarily require mattress removal, improved lifting systems would be needed where multiple lifts are contemplated.

Swift currents made precise deployment difficult. Further improvements in the method of deployment are suggested in similar environments.

A.28.8 Reference

EPRI. 2011. *Capping for Coal Tar-Impacted Sediments: An In-Situ Evaluation of Effectiveness and Implementability* (Phase II – Design, Installation and Monitoring)., Palo Alto, CA.

A.29 Hudson River, NY

A.29.1 Summary

Environment:	Freshwater
Contaminants of Concern:	PCBs: hotspots were 50 ppm or greater
Final Remedy:	Cofferdams and sheet piling was used to dewater some of the sediment throughout the river. Contaminated sediment was taken to multiple off-site facilities (Michigan, Texas, and Idaho).

A.29.2 Site Description

Year: 2009-present

Water depth: 0–25 ft

Target volume: 2.4 million yd^3

Actual volume removed (as of 2011): 660,000 yd^3

Contaminated sediment area: 43 miles

A.29.3 Remedial Objectives

Remove substantial amount of PCBs in river.

A.29.4 Remedial Approach

A mechanical dredge with an environmental bucket was used. The area was divided into 8 pools by 8 dams and locks. Forty hotspots are most closely being investigated.

A.29.5 Monitoring

The SWDA standard of 500 ppt used and was exceeded 3 times. Temporary shutdowns when suspension levels were too high. Silt curtains were implemented and dredging continued.

RAOs/project objectives achieved? Dredging was slowed due to logging debris in river. There is currently ongoing dredging at this site. "Spoils" sites have been covered with low permeability soil caps, with 150,000 tons of cover used for backfill and caps.

A.29.6 References

Cashman. http://www.jaycashman.com/project-details.php?ID=199.

The Hudson River Dredging Project. Dredging of the Hudson River Chronology. http://www.hudsondredging.com/dredging-of-the-hudson-river-chronology/.

EPA Hudson River PCBs Superfund Site Dredging Data Website. http://www.hudsondredgingdata.com/

U.S. EPA. First Five-Year Review Report for Hudson River PCBs Superfund Site. June 2012. http://www.hudsondredgingdata.com/documents/pdf/Hudson-River-First-FYR.pdf.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.smwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.30 Ketchikan Pulp Company, AK

A.30.1 Contacts

Regulatory Contact:
Karen Keely
US Environmental Protection Agency, Region 10:
206-553-2141
keely.karen@epa.gov

A.30.2 Summary

Environment:	Cove
Scale:	Full
Contaminants of Concern:	Arsenic, PCBs, lead, petroleum compounds, ammonia, hydrogen sulfide, and 4-methylphenol
Source Control Achieved Prior to Remedy Selection?	Yes
Final Remedy:	Removal, Capping, MNR
Expected Recovery Time:	Remedy complete-7 years
MNR viewed as a success?	Yes

A.30.3 Site Description

The former KPC mill is located on the northern shoreline of Ward cove, approximately 5 miles north of Ketchikan, Alaska. Ward Cove is located on the north side of Tongass Narrows and is approximately 1 mile long with a maximum width of 0.5 mile. The orientation of the Cove is southwest to northeast. The Cove is bounded by Slide Ridge to the north and Ward Mountain to the south. Surrounding terrain is mountainous and forested. The shoreline of the Cove is mostly rocky and relative steep. Ward Creek is the major source of freshwater inflow; the creek enters the head of the Cove. The primary sources of contamination at this site are historical wastewater discharges from the former Ketchikan Pulp Company (KPC) pulp mill.

The KPC facility began operations as a dissolving sulfite pulp mill in 1954 and discharged pulp mill effluent to Ward Cove until March 1997, when pulping operations terminated. Equipment associated with the pulp mill operations has been dismantled and removed from the site. In November 1999, the KPC upland mill property and patented tidelands in Ward Cove were sold to Gateway Forest Products Company, Inc. (Gateway). Gateway planned to use the site to operate a sawmill and a veneer mill, producing lumber and veneer, chips for pulp, and hog fuel as a byproduct.

A.30.4 Remedial Objectives

RAO(s)/Project objectives:

- Reduce toxicity of surface sediments
- Enhance recolonization of surface sediments to support a healthy marine benthic infauna community with multiple taxonomic groups.

A.30.5 Remedial Approach

Final selected remedy: Dredging, capping, MNR

The selected remedy consists of the following actions:

- Placement of a thin-layer cap (approximately 6 to 12 inches) of clean, sandy material over approximately 27-acres with the area of concern (AOC).
- Dredging of approximately 8,701 yd^3 of bottom sediments from an area in front of the main dock and an area near the shallow draft barge berth area to accommodate navigational depths, with disposal of the dredged sediments at an upland location. The dredging volume estimate was less than expected because native, clean sediments were encountered at a shallower depth than anticipated. After dredging, a thin-layer cap of clean, sandy material was constructed in dredged areas where native sediment or bedrock was not reached during dredging.
- Approximately 680 tons of sunken logs were removed from the bottom of Ward Cove in areas to be dredged.
- Natural recovery was selected as the remedy in areas where neither capping nor mounding is feasible. In areas where thin-layer placement was not constructed, allowed for monitored natural recovery in approximately 52 acres.
- Institutional controls requiring that post-remediation activities within the AOC that materially damage the thin-layer cap will be required to redress such damage, at the direction of USEPA.

The selected remedy represents the best balance of tradeoffs under the Superfund evaluation criteria. Because the problem sediment in Ward Cove did not pose unacceptable risk to human health or to wildlife through bioaccumulation of chemicals from sediments, the key concern was how well the selected remedy addressed toxic risks to benthic communities living in the sediments. Placement of a thin-layer cap, or dredging of problem sediment followed by capping provided a suitable habitat for benthic communities. The selected remedy was also more cost effective than removing all of the problem sediment.

Other considerations in remedy selection include the following:

- Available in situ treatment technologies would be difficult to implement and may not be effective on the scale required for sediments in Ward Cove.
- Costs for in situ remediation would be high and there would likely be little or no improvement in ecological conditions within Ward Cove.
- Dredging of problem sediments followed by separation of fine wood debris from the dredged sediments would be difficult to implement (requiring significant material handling), would generate large amounts of wastewater that would require treatment, and would be extremely costly while producing little or no environmental benefit.

A.30.6 Monitoring Approach

Monitoring elements: The monitoring program will evaluate three major indicators of sediment quality including the sediment chemistry, sediment toxicity, and macroinvertebrate communities.

The primary objectives of the Ward Cove monitoring program are as follows:

- Compare sediment toxicity in the thin capped and natural recovery areas in the AOC with sediment toxicity in reference areas located elsewhere in the cove.
- Compare the characteristics of benthic communities in thin capped and natural recovery areas in the AOC with the characteristics of communities in reference areas located elsewhere in the cove.
- Evaluate temporal trends in sediment toxicity in the thin capped and natural recovery areas of the AOC.
- Evaluate temporal trends in the characteristics of benthic macroinvertebrate communities found in the thin capped and natural recovery areas of the AOC.
- Evaluate chemical concentrations and their relationship to sediment toxicity and benthic community structure.

RAOs/project objectives achieved? Remediation activities were completed in 2001. In 2009, USEPA approved the final 2007 Monitoring Report for Sediment Remediation in Ward Cove, Alaska. The USEPA concurred that the RAOs for the sediment remedy were achieved, that the remedy is protective of human health and the environment, and monitoring pursuant the long-term monitoring and reporting plan is no longer necessary.

A.30.7 References

USEPA Region 10, the Pacific Northwest, Ketchikan Pulp Company. http://yosemite.epa.gov/r10/cleanup.nsf/1a16218b78d8c4d58825674500015b42/2dd5ab7462e4f004882567b30057eb7b!OpenDo

EPA Superfund Record of Decision, Ketchikan Pulp Company. http://www.epa.gov/superfund/sites/rods/fulltext/r1000035.pdf.

A.31 Kokomo and Wildcat Creeks, IN

A.31.1 Summary

Environment:	Freshwater
Scale:	Full
Contaminants of Concern:	PCBs averaged <10 times the criteria, PAHs detected up to 10 times the criteria, Arsenic detected 3–10 times criteria, Beryllium up to 10 times the criteria.
Final Remedy:	Coarse material gravity dewatered; fines dewatered by solidification. On-site lined dewatering pads, water treated on site using sand and granular AC before release to river. 51,000 yd^3 of material landfilled; treated off-site if necessary for metals and PCBs; disposed in CAMU; ESD 2005–Creek solids (PCB and VOC) disposed off-site at existing permitted facility.

A.31.2 Site Description

Continental Steel property, OU 3 at Kokomo and Wildcat Creeks, IN

Year: 2007

Water Depth: 1-4 ft

Target Volume:

- Kokomo Creek: 7,760 yd^3
- Wildcat Creek: 8,240 yd^3
- Total: 16,000 yd^3

Actual Volume Removed: 22,467.12 tons

A.31.3 Remedial Objectives

Remove contaminated sediment within the 2 mile stretch of the creek. Contaminated sediment thickness ranges from 0.4 to 2.17 ft.

A.31.4 Remedial Approach

Kokomo Creek was dewatered, so resuspension was not an issue. Dry excavation was completed with conventional earth moving equipment. Hydraulic dredging was completed with a suction vacuum dredge. The amount of water flowing through Wildcat Creek made mechanical dredging difficult, so sediment in Wildcat creek was drawn out with a vacuum.

At Wildcat Creek turbidity monitoring was conducted using sediment trap placement and sampling. Data showed very little resuspension of contaminated sediments

A.31.5 Monitoring

SWAC immediately after dredging:

- PCBs: 3 ppm
- PAHs: 7 ppm
- Arsenic: 19 ppm
- Beryllium: 0.840 ppm

Concentrations are lower than pre-dredging.

MNR is being used to ensure the creeks remain at a safe level of contaminants.

A.31.6 References

USEPA Superfund Record of Decision: Continental Steel Corp. USEPA ID: IND001213503. Sep 1998. http://www.epa.gov/superfund/sites/rods/fulltext/r0598091.pdf.

USEPA Superfund Explanation of Significant Differences: Continental Steel Corp. USEPA ID: IND001213503. Sep 2005. http://www.epa.gov/superfund/sites/rods/fulltext/e0505037.pdf.

Indiana Department of Environmental Management. First Five-Year Review Report for Continental Steel Superfund Site City of Kokomo. Jul 2002. http://www.epa.gov/superfund/sites/fiveyear/f02-05013.pdf.

Indiana Department of Environmental Management. Second Five Year Review Report for Continental Steel Superfund Site City of Kokomo. Sep 2007. http://www.epa.gov/superfund/sites/fiveyear/f2007050001940.pdf.

A.32 Koppers Barge Canal, SC

A.32.1 Contacts

Regulatory Contact: Craig Zeller, USEPA (zeller.craig@epa.gov)

A.32.2 Summary

Environment:	Marine Embayment
Scale:	Full
Contaminants of Concern:	PAHs (primary), arsenic, dioxin, pentachlorophenol, lead, chromium, and copper
Source Control Achieved Prior to Remedy Selection?	No
Final Remedy:	MNR for the Barge Canal (3.2 acres), capping and dredging portions of the Ashley River (5.3 acres)
Expected Recovery Time:	5 years
MNR viewed as a success?	Yes

A.32.3 Site Description

The Koppers Co., Inc. Barge Canal site lies to the west of the Ashley and Cooper Rivers, in northern Charleston, South Carolina. The site covers approximately 102 acres and includes land, drainage ditches, a barge canal, estuarine marshes, and a portion of the Ashley River. The primary source of the contaminants is from past direct discharges and releases from wood treating operations, as well as past and fugitive releases from upland soils and groundwater.

From the 1940s to 1977, an approximately 45-acre segment of this site was used for wood treatment operations. Creosote was the primary preservative; however, pentachlorophenol and copper-chromium-arsenate were also used. Water from creosote separation tanks were discharged into ditches that lead to the Ashley River.

From 1953 to 1968, Koppers leased approximately 4 acres to the south of its property where it disposed of sawdust, bark, and other wood waste materials. In 1984, the 3.2 acre Barge Canal was dredged eastward from the Ashley River to the Koppers property. This resulted in exposure of treated (creosote) wooden poles, highly turbid water, an oily sheen on the Ashley River and a fish kill ¼ mile downstream of the canal. It is believed that the canal was dredged through the area formerly leased by Koppers.

CSM summary: The Ashley River is naturally elevated in suspended solids (silts/clays) which are deposited within the quiescent environment of the Barge Canal with each tidal cycle. Consequently, the primary natural recovery process at the Koppers site is physical isolation of contaminated sediments via the natural deposition of suspended sediment from the Ashley River (> 2 cm/year). Lines of evidence collected to demonstrate this include transects of sediment cores which show a decreasing trend in the concentration of PAHs over time, and deposition modeling, bathymetric and hydrographic surveys, and aerial photography.

A.32.4 Remedial Objectives and Approach

Concerns for this case study include both ecological and human health risks:

- Ecology: risks for benthic communities, fish, mammals and birds
- Human health: industrial and off-site resident exposures

The 1998 ROD did not define specific RAOs. The ROD stated that "the primary evaluation criteria for sediments in the Ashley River, Barge Canal and tidal marshes is the long-term protection of ecological resources."

Final selected remedy: MNR for the Barge Canal (3.2 acres), capping and dredging portions of the Ashley River (5.3 acres) adjacent to the Barge reach.

Lines of evidence collected during the remedial design phase established that physical isolation was a significant natural recovery process. This finding changed the initial subaqueous capping remedy decision outlined in the 1998 ROD to MNR, as detailed in the 2003 Explanation of Significant Differences.

The primary lines of evidence used to investigate MNR and physical isolation included a two-dimensional hydrodynamic and sediment transport modeling study, bathymetric surveying to document sedimentation rates, and aerial photography to document vegetation encroachment suggestive of sedimentation.

A.32.5 Monitoring

Monitoring elements: Monitoring focused on two areas: physical isolation and risk reduction. Elements covering physical isolation include bathymetric surveys to determine net sediment deposition and aerial photography to document sedimentation and vegetation encroachment. Risk reduction monitoring includes surface sediment chemistry analysis to monitor concentration of total PAHs in sediment samples.

The Second Five-Year Review determined that the MNR remedy is adequately protective and recommended discontinuing monitoring of sediment and vegetation encroachment in the Barge Canal.

Center of Koppers Barge Canal at Low Tide

2003 2004 2007

A net sediment accumulation of 0.5-2 ft was demonstrated in the central portion of the Barge Canal and for some areas net accumulation reached approximately 5 ft. Aerial photography showed a net accumulation of approximately 0.319 acres of vegetation between 2000 and 2004 which increased to 0.80 acres between 2000 and 2007. Finally, PAH concentrations have been decreasing, and the last three sampling events (2003, 2004, and 2007) were within the background range for Ashley River sediment.

Temporal Trend in Sediment PAH's

Year	Mean Total PAH (mg/kg)
1994 RI	138.4
2003	28.6
2005	6.6
2007	2.7

*Background concentration range = 2 - 48 mg/kg total PAH.

Expected recovery time: 5 years

Monitoring cost: Because total PAH concentrations are at background levels and unlikely to decrease further, and that marsh vegetation continues to develop due to the dominant depositional environment, no additional monitoring of sediment quality in the barge canal is warranted.

RAOs/project objectives achieved? Overall the MNR implemented and monitored at the Former Koppers Barge Canal is viewed as a success.

A.32.6 Costs

The choice of MNR over the alternative remedial plan (subaqueous capping) saved a total of $447,000 that was estimated if subaqueous capping was implemented in the Barge Canal. As the final estimated remedial cost for the whole site was 20.4 million dollars, the choice of MNR for the Barge Canal saved approximately 2.2% of the final remedial costs (including O&M).

A.32.7 Advantages and Limitations

- Site Specific Challenges:
  - Regulatory: MNR is an acceptable choice for a remedy under the Superfund process. Based on review of monitoring data, the MNR remedy for the barge canal sediments is considered to be “adequately protective."
  - Technical: Sampling of the Barge Canal was dangerous as the sediments are soft and deep; slope of canal sediments very shallow so timing of deployment of open water work needed to be exact to avoid stranding of vessels.
  - Community: Community notification of the Five-Year Review (USEPA 2008a) was provided in the Charleston Post & Courier on March 21, 2008. A copy of the notification is provided in Appendix C of the Five-Year Review. The USEPA Remedial Project Manager and Community Involvement Coordinator did not receive any calls or comments from the community related to the Five-Year Review process.

- Acceptance: USEPA has conducted a range of community involvement activities at the Koppers Co., Inc. (Charleston Plant) site to solicit community input and to ensure that the public remains informed about site activities throughout the site cleanup process. Outreach activities have included public notices and information meetings on cleanup progress and activities.

A.32.8 References

USEPA, 2008. Five Year Review Report: Second Five Year Review for the Koppers Co., Inc. (Charleston Plant) NPL Site Charleston, Charleston County, South Carolina. Prepared By: Craig Zeller, P.E., Remedial Project Manager, USEPA Region 4 Superfund Division. June 2008. http://www.epa.gov/superfund/sites/fiveyear/f2008040002381.pdf.

USEPA WebsiteRegion 4.

A.33 New Castle County, Koppers Site, DE

A.33.1 Contacts

Regulatory Contact: USEPA (Region III)
EPA ID# DED980552244
Site Contact: Matthew T. Mellon

A.33.2 Summary

Environment:	Tidal and non-tidal freshwater wetlands, tributary, and river system
Scale:	Full
Contaminants of Concern:	NAPL and TPAH
Source Control Achieved Prior to Remedy Selection?	No
Final Remedy:	Source control, excavation, and capping
MNR viewed as a success?	Not applicable

A.33.3 Site Description

The entire Koppers Newport Plant is a Superfund site located in the northern part of New Castle County, Delaware, southwest of the town of Newport and northwest of the Route I-95 and route 141 interchange. The site is comprised of over 300 acres and currently consists of old field/grass and shrub uplands (approximately 163 acres), forested areas, forested wetlands, non-tidal and tidal freshwater wetlands (> 137 acres), and bald eagle foraging habitat. The tidal wetlands drain individually into Hershey Run, White Clay Creek, and the Christina River. Hershey Run drains into White Clay Creek, which then flows into the Christina River. White Clay Creek is Delaware's only "National Wild and Scenic River."

The site is bordered by high-speed railroad lines. Beyond the rail lines are a former municipal sewage treatment facility, an industrial property, and a residential area. The site is bordered to the east by the former DuPont Holly Run Plant and the Christina River. White Clay Creek and Hershey Run border the site to the south and west, respectively.

The primary sources of contamination at this site are creosote constituents (total PAHs), metals (not site-related), and PCBs (not site-related) present in sediment. PCBs concentrations in sediment have resulted in a fish advisory of Hershey Run marsh that has been in place since 1996. Free product (NAPL) is present in groundwater, and groundwater impacts include creosote, BTEX, PCP, Dioxins, and pesticides.

The Koppers' Site served as a creosote wood treating operation from 1929 through 1971. Approximately 1,000,000 gallons of creosote were stored on site at any one time. The site has remained largely inactive since operations ceased in 1971.

The primary material used in the wood treatment processes was a creosote/coal tar solution, which was used to preserve railroad ties, telephone poles, and other wood products. Although to a much smaller degree, pentachlorophenol (PCP) was also used to treat wood. Throughout a large area of the site (approximately two-thirds of the operations area), an array of railroad tracks provided for the movement of wood and materials to and from the site with the primary handling occurring in the Process and Drip Track Areas.

The Process Area was used for the application of wood preservatives and contained various wood-treatment equipment and associated structures. This area also provided storage for approximately 1,000,000 gallons of creosote and other process-related materials. The treatment consisted of heating and pressurizing tanks filled with creosote and wood, forcing the creosote into the wood. After treatment, the freshly-treated wood products were temporarily allowed to cure and drip dry in the Drip Track Area prior to transfer to the Wood Storage Area. The Fire Pond was created as a source of water for firefighting purposes.

The site was identified as a potential hazardous waste site in 1979. The site was added to the NPL list on August 30, 1990, and Beazer and DuPont signed an agreement to conduct a RI/FS in 1991.

CSM summary: A human health and ecological risk assessment were completed for the site. The human health risk assessment indicated an unacceptable risk to future industrial workers from ingestion of soil from benzo(a)pyrene and cPAH but did not suggest a risk related to sediment. The ecological risk assessment suggested that sediment concentrations of 197.6 mg/kg were lethal to test organisms (benthos), and sediment concentrations of TPAH <82.3 mg/kg did not cause mortality.

The site areas of concern were determined to have both ecological and human health risks. Geographical comparison of risk indicated that ecological risk cleanup goals were protective of human health risks as well. Therefore, the cleanup goals for the site were based on ecological risk assessment conclusions (sediment: 150 mg/kg TPAH). The 150 mg/kg TPAH value for sediment and seasonally flooded soil was the rounded off geometric mean of the range of no observed adverse effect level (NOAEL) and lowest observed adverse effect level (LOAEL) values (82.8 and 197.6).

A.33.4 Remedial Objectives

RAOs/project objectives include:

- Prevent current or future direct contact with contaminated sediments that would result in unacceptable levels of risk to ecological receptors by reducing levels of TPAH concentrations to below 150 mg/kg in sediment. Soil that was to be converted to wetlands required a cleanup goal of 150 mg/kg.
- Prevent unacceptable human health risk due to contaminated groundwater.

- Minimize the ongoing contamination of groundwater from presence of NAPL through removal and/or containment.
- Maximize the area of wetlands available for various re-use options (for example, wetlands banking by Delaware Department of Transportation).

A.33.5 Remedial Approach

Final selected remedy: Complete excavation, consolidation and capping of all contaminated sediment, subsurface groundwater barrier wall around consolidation area (a) with passive NAPL recovery, excavation of NAPL-contaminated aquifer material outside of consolidation areas, re-channelization of Hershey Run, wetlands mitigation, and monitored natural attenuation of groundwater contamination.

The sediment component of the remedy was necessary to protect trespassers and ecological receptors. The remedy involved complete excavation and consolidation of the impacted sediment into an on-site landfill of contaminated sediments containing TPAH concentrations above 150 mg/kg. Areas excavated included what was known as the Fire Pond, South Pond, K Area, West Central Drainage Area, lower Hershey Run, and the marsh adjacent to the upper portion of Hershey Run. The depth of the excavation ranged from 0 to 13 ft with an average of 2 to 4 ft. Restoration activities would take place as appropriate to provide suitable ecological habitat. Only minor backfilling, if at all, would be required, thereby increasing the diversity of the wetland types.

The landfill would be located in an area of the worst NAPL contamination and would include the groundwater barrier wall and collection system to prevent further migration of the NAPL contamination. The upper portion of Hershey Run would be re-channelized to allow for installation of sheet pile and passive NAPL recovery. Any wetland acreage that was lost would be replaced on site. Approximately one and one-half miles of Hershey Run would be dredged along with approximately 4 acres of wetlands. It was estimated that a total of approximately 80,000 yd^3 of stabilized sediments would be added to the consolidation area (includes a 15% increase in volume for stabilization to improve soil/sediment properties to support a cap).

This remedy was selected based on the following criteria:

- addresses risk present in all site media
- addresses all source areas, stopping current releases and minimizing potential for future releases
- provides for maximum flexibility for future reuse options
- provides for overall protection of human health and the environment
- balances protectiveness and cost (is over $200 million less costly than other FS alternatives)
- minimizes disturbances to surrounding community
- has the support of state agencies.

Expected recovery time: NA

A.33.6 Costs

Project capital costs: $45,260,000 (includes soil and groundwater remedy costs)

Projected operation and monitoring costs: $48,155,000 (includes soil and groundwater remedy costs)

A.33.7 References

Mellon, M. 2004. Koppers (Newport, De) Superfund Site - National Remedy Review Board Presentation. USEPA (Region III). Washington, D.C.

USEPA. 1997. Ecological Risk Assessment: Koppers (Newport, DE) Site. USEPA ERT. Edison, NJ (Mark Sprenger - POC).

A.34 Lavaca Bay Area, TX

A.34.1 Summary

Environment:	Marine
Scale:	Full
Contaminants of Concern:	Hg: SWAC 0.7 ppm PAHs: Max 137.4 ppm
Final Remedy:	Hydraulic Cutterhead dredge and MNR. Dewatering method was gravity settling. Contaminated sediment was taken to an off-site facility 2.8 miles away at Point Comfort, TX.

A.34.2 Site Description

Lavaca, Cox, and Western Matagorda bays

Cox Creek, Cox Cove, Cox Lake

400-acre artificial dredge spoils island

Year: 1999

Target volume: 184,000 yd^3

Actual volume removed: 79,500 yd^3

Contaminated sediment area: 80,000 acres

A.34.3 Remedial Objectives

Sediments in fringe marsh habitat: < 0.25 ppm, in open-water: < 0.5 ppm

A.34.4 Remedial Approach

Hydraulic cutter head dredge; monitored natural recovery to verify a drop in concentrations in biota.

A.34.5 Monitoring

Silt curtains were in place to contain suspended sediment. Turbidity monitoring was performed downstream to measure the success of silt curtains. Slightly elevated mercury levels were shown to occur periodically.

Two phases were done: partial implementation as part of a treatability study, followed by actual remediation.

A.34.6 References

EPA Superfund Record of Decision. Alcoa (Point Comfort)/Lavaca Bay EPA ID: TXD008123168 OU 01. Dec 2001. http://www.epa.gov-/superfund/sites/rods/fulltext/r0602001.pdf.

Record of Decision. Alcoa (Point Comfort)/Lavaca Bay Site CERCLIS# TXD 008123168. Dec 2001. http://www.epa.gov/region6/6sf/pdffiles/alcoa_lavaca_final_rod.pdf.

Five-Year Review Report. Alcoa (Point Comfort)/Lavaca Bay Superfund Site EPA ID# TXD 008123168. June 2011. http://www.epa.gov/superfund/sites/fiveyear/f2011060004079.pdf.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.35 Lavaca Bay, Point Comfort, TX

A.35.1 Contacts

Regulatory Contact: USEPA

A.35.2 Summary

Environment:	Estuarine embayment
Scale:	Full
Contaminants of Concern:	Mercury, PAHs, methylmercury
Source Control Achieved Prior to Remedy Selection?	Yes
Final Remedy:	MNR (1700 acres), dredging (280,000 yd^3)
Expected Recovery Time:	10-15 years
MNR viewed as a success?	Not yet determined

A.35.3 Site Description

The Lavaca Bay site is part of the larger Matagorda Bay system located in southeastern Texas, adjacent to the Gulf of Mexico. It is a shallow bay with an average depth of about 4 ft and covers approximately 60 square miles. Dredge Island is a 420 acre area located within the bay made up of dredge materials. The area surrounding this island is known as the "Closed Area." The primary sources of contamination at this site include past direct discharges and releases from metal refining and chlor-alkali processes.

Aluminum smelting was begun by the Aluminum Company of America (Alcoa) in 1948 and shut down in 1980. Bauxite refining began there in 1958 and continues to this day. Additional past operations have included cryolite processing, chlor-alkali production of sodium hydroxide and chlorine (1966-1979), and coal tar processing (by Witco Chemical Corporation, 1964-1985).

An offshore gypsum lagoon located on Dredge Island was used to hold mercury-containing wastewater from the chlor-alkali process. The overflow was then discharged to Lavaca Bay after a settling period. The Texas Water Quality Board ordered Alcoa to limit its mercury levels in wastewater discharges after it found elevated levels of mercury in crabs during the 1970s. In 1980, fishing was banned in the Closed Area. In 2000, this area was reduced following a decrease in concentrations of mercury in fish tissue.

This site was added to the National Priorities List in 1994. An ROD was issued for the site by the USEPA in 2001. A Consent Decree was signed by Alcoa with USEPA in 2005.

CSM summary: The primary natural recovery processes at the Lavaca Bay site is physical isolation. Two primary lines of evidence were collected to support this. A radiochemistry study was conducted to estimate the vertical extent of mercury contamination in sediments and sedimentation rates. Sedimentation rates vary between 0.3 and 2.0 cm per year. Hurricane scour modeling was conducted to determine the risk of sediment transport and the subsequent redistribution of mercury during future hurricane events. It was found that high-energy events would have negligible effects on mercury redistribution.

A.35.4 Remedial Objectives

The risk assessment showed unacceptable risks to human and ecological receptors from PAHs and mercury.

The RAOs for the site target a reduction in mercury levels in fish tissue to create the same risk level throughout the bay that would have existed without the Point Comfort Operations Plant. RAOs include:

- Eliminate or reduce mercury and PAH loading from ongoing unpermitted sources to Lavaca Bay to the maximum extent practical.

- Reduce mercury concentrations in surface sediments of sensitive habitats to an appropriate level.
- Reduce mercury concentrations in open-water surface sediments that serve as a pathway for introducing mercury into the food web to an appropriate level. Reduce PAH concentrations in sediments to below 44.8 mg/kg total PAHs, the effects range median benchmark established by the National Oceanic and Atmospheric Administration.

Cleanup levels for mercury in sediments are as follows:

- 0.5 mg/kg mercury for sediments in open-water habitats
- 0.5 mg/kg mercury for sediments in marsh habitats

A.35.5 Remedial Approach

Final selected remedy: MNR (1700 acres), dredging (280,000 yd^3)

Components of the remedy included:

- Dredging of the most highly contaminated sediments and installation of a DNAPL collection or containment system (Witco Area).
- Extraction and treatment of chlor-alkali process area groundwater and monitoring of surface water to evaluate the effectiveness of the hydraulic containment system.
- MNR of remaining affected areas (aerial extent not available).
- Institutional controls to manage human exposure to fish and shellfish.
- Long-term annual monitoring of mercury in surface sediments, fish, and shellfish of the bay to confirm the natural recovery of sediment and fish tissue to acceptable levels.

The initial remedy for this site had called for EMNR (with thin-layer capping) for sediments north of Dredge Island to eliminate an ongoing source of PAHs to the bay. Monitoring determined that natural recovery processes alone were sufficient. Currently MNR has been implemented in approximately 1700 acres of the Closed Area.

Primary lines of evidence collected to support physical isolation include radioisotope analysis and sediment age dating to document sedimentation rates. In addition, modeling was used to predict sediment stability during a hurricane.

A.35.6 Monitoring

Monitoring elements: Monitoring activities focused on analyzing risk reduction and includes monitoring of mercury in fish tissue as well as surface sediment chemistry.

RAOs/project objectives achieved? Mercury concentrations in sediments are reaching desired cleanup levels. Five marshes have met cleanup levels since 2005. There remains some localized open water sediment areas that are not recovering as expected, as well as locally elevated mercury concentrations in some marshes. In addition, while mercury concentrations in fish and crab tissue experience yearly fluctuations they are still elevated compared to the reference area.

Expected recovery time: 10-15 years

Projected monitoring costs: $1,660,000

RAOs/project objectives achieved? Overall, it is not yet determined if MNR is viewed as a success.

A.35.7 References

EPA Superfund Record of Decision. Alcoa (Point Comfort)/Lavaca Bay EPA ID: TXD008123168 OU 01. Dec 2001. http://www.epa.gov-/superfund/sites/rods/fulltext/r0602001.pdf.

Record of Decision. Alcoa (Point Comfort)/Lavaca Bay Site CERCLIS# TXD 008123168. Dec 2001.http://www.epa.gov/region6/6sf/pdffiles/alcoa_lavaca_final_rod.pdf.

Five-Year Review Report. Alcoa (Point Comfort)/Lavaca Bay Superfund Site EPA ID# TXD 008123168. June 2011. http://www.epa.gov/superfund/sites/fiveyear/f2011060004079.pdf.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

Global Restoration Network, Case Study Detail. http://www.-globalrestorationnetwork.org/database/case-study/?id=287.

A.36 Little Elk Creek, Elkton, MD

A.36.1 Contacts

Regulatory Contacts:
John Epps,
215-814-3144
epps.john@epa.go

Kim Lemaster
410-537-3440
klemaster@mde.state.md.us

A.36.2 Summary

Environment:	Creek
Scale:	Full
Contaminants of Concern:	Solvent DNAPLs
Source Control Achieved Prior to Remedy Selection?	Groundwater pump and treat implemented at same time as stream remedy
Final Remedy:	Excavation, low permeability cap

A.36.3 Site Description

The Galaxy/Spectron Inc., Little Elk Creek, site is located on approximately eight acres near Elkton, Maryland, in a rural residential area. Both light and dense NAPLs (LNAPLs and DNAPLs, respectively) were released while the solvent recycling operation was active, resulting in contaminated soil, overburden groundwater, bedrock groundwater, and DNAPL seeps along the western bank of Little Elk Creek.

The site was operated as a paper mill until it was destroyed by fire in 1954. Solvent recycling operations occupied the site from 1962 to 1988. The liquid materials processed at the facility included volatile organic compounds (VOCs) such as chlorofluorocarbons, halogenated ethenes and ethanes, chlorobenzenes (denser than water), and various alkanes and aromatic hydrocarbons (less dense than water).

CSM summary: The CSM indicated residual DNAPL in the shallow soil being released from an unlined storage lagoon and leaks from the processing equipment. Contamination at the site was released into the soil, and much of it migrated into the fractured bedrock. Once DNAPLs enter the groundwater, they act as a major source of groundwater contamination (via dissolution) and surface water contamination (due to discharge of contaminated groundwater and/or movement of DNAPLs). Site receptors include individuals who may be exposed to the contaminants in the soil and groundwater.

A.36.4 Remedial Objectives

Numerous organic and inorganic chemicals pose threats to human health and ecological receptors in Little Elk Creek. USEPA has established the following RAOs to mitigate and/or prevent existing and future potential threats to human health and the environment:

- Continued operation and maintenance of the constructed groundwater containment system, so that federal AWQC for consumption of fish and drinking water are not exceeded within Little Elk Creek, immediately downstream of the groundwater containment system. This action is necessary to address potential risks to human health and ecological risks that may occur if the operation were discontinued and contamination were to enter Little Elk Creek.
- Continued operation and maintenance includes ensuring that the groundwater treatment plant has adequate capacity. The maintenance of the liner is also necessary to prevent the re-establishment of the seeps along the creek banks, which existed prior to the installation of the liner.

A.36.5 Remedial Approach

Final selected remedy: Excavation, low permeability cap, and groundwater treatment

Approximately 2,000 yd^3 of affected stream sediments were excavated from Little Elk Creek in 1998, and a Stream Isolation/Ground Water Collection and Treatment System (GWTS) was constructed in 1999 to contain and intercept VOC-bearing groundwater from the overburden and bedrock thereby eliminating discharge to the stream. The stream isolation used an engineered cap consisting of a polyethylene membrane-backed geosynthetic clay liner (GCL), Bentomat CL™. The GCL was overlain by a geotextile and gabion basket with stone and sand fill for erosion protection.

Additional upland actions included a RCRA modified cap and in situ chemical reduction treatment of groundwater.

USEPA has determined that the selected remedy provides the best balance of tradeoffs among the balancing criteria (long-term effectiveness and permanence; reduction in toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; and cost) while considering state and community acceptance.

A.36.6 Monitoring

Collected groundwater is treated, and thus monitored prior to discharge to Little Elk Creek, to comply with the requirements of the NPDES program and the Maryland discharge limitations and monitoring requirements of 100 ppb total VOCs.

Routine sampling is performed in the creek immediately downstream of the groundwater containment system for VOCs and semi-VOCs. Federal Ambient Water Quality Standards for consumption of fish and drinking water are required to be met in Little Elk Creek.

RAOs/project objectives achieved? The seeps have been continually captured and treated by the stream isolation/GWTS and no longer contribute to contamination in the creek. Because of the improvements in stream water quality due to the stream isolation/GWTS, restrictions on the use of the stream have been removed.

A.36.7 Costs

The geosynthetic clay liner material cost was $35,000. The annual operation and maintenance cost (in 2004 dollars) for the groundwater treatment system was estimated at $360,000.

A.36.8 Advantages and Limitations

Site-specific challenges at this site include the following:

- Regulatory—The Maryland Department of Environment (MDE) believed that an upland RCRA modified cap was necessary to minimize the impact of infiltration on groundwater treatment.
- Technical—After a storm in 2000, the groundwater treatment system was found to be undersized causing the creek liner to become buoyant until the pressure on the liner could be relieved. To correct the situation, the groundwater system treatment capacity was increased

three-fold, pumped groundwater storage capacity added, and a RCRA modified cap was installed upland to minimize infiltration.

- Community—The local community has not commented specifically on the selected alternative but generally stated its concern for safety of drinking water, a quick cleanup of the site, and a future use that may benefit the community.
- Acceptance—The USEPA believes the selected remedy addresses many of the issues raised by the MDE and local community. The selected remedy helps protect drinking water, provides flexibility for future use, and could be implemented quickly.

A.36.9 0 References

U.S. Environmental Protection Agency, Mid-Atlantic Superfund, NPL Fact Sheet, Spectron Inc. http://www.epa.gov/reg3hwmd/npl/MDD000218008.htm.

U.S. Environmental Protection Agency, Region 3, Spectron Inc. Superfund Site Record of Decision Operable Unit 1, Sept. 2004. http://www.epa.gov-/reg3hwmd/npl/MDD000218008/rod/2004-09-16/20040916Spectron%20RODFINAL.pdf.

Maryland Department of Environment, Facts about Galaxy/Spectron Site (NPL site). http://www.mde.state.md.us/assets/document/brownfields/spectron.pdf.

A.37 Love Canal, Niagara Falls, NY

A.37.1 Contacts

EPA Western New York Public Information Office, 716-551-4410 ext.186

A.37.2 Summary

Environment:	River/Creek
Scale:	Full
Contaminants of Concern:	Volatile organics, dioxin, metals, PAHs, pesticides
Source Control Achieved Prior to Remedy Selection?	Yes
Final Remedy:	Excavation
MNR viewed as a success?	NA

A.37.3 Site Description

Location: The Love Canal site is located in the southeast corner of the city of Niagara Falls, New York. The 70-acre site is enclosed by a fence. It encompasses the original 16-acre hazardous waste landfill and a 10-square-block area surrounding it. The site is approximately ¼ mile north of the Niagara River and 3 miles upstream of the intake tunnels for the Niagara Falls water treatment facility. The primary source of contamination at this site was improper disposal of over 21,000 tons of various chemical wastes.

The site includes the original canal that was excavated by William Love in the 1890s for a proposed hydroelectric power project but was never implemented. Beginning in 1942, the landfill was used by Hooker Chemicals and Plastics (now Occidental Chemical Corporation) for the disposal of over 21,000 tons of various chemical wastes, including halogenated organics, pesticides, chlorobenzenes, and dioxin. Dumping ceased in 1952, and in 1953, the landfill was covered and deeded to the Niagara Falls Board of Education (NFBE). In 1950, the 93rd Street School was built less than one mile northwest of the Love Canal, and in 1954, the 99th Street School was built adjacent to the middle portion of the Canal. Subsequently, the area near the landfill was extensively developed, including the construction of numerous homes.

Problems with odors and residues, first reported in the 1960s, increased during the 1970s, as the water table rose, bringing contaminated groundwater to the surface. Studies indicated that numerous toxic chemicals had migrated into the surrounding area directly adjacent to the original landfill disposal site. Runoff drained into the Niagara River, approximately three miles upstream of the intake tunnels for the Niagara Falls water treatment plant. Dioxin and other contaminants migrated from the landfill to the existing sewers, which had outfalls into nearby creeks.

Approximately 950 families were evacuated from a 10-square-block area surrounding the landfill. FEMA was directly involved in property purchase and residential relocation activities. In 1980, the neighborhoods adjacent to the site were identified as the Emergency Declaration Area (EDA), which is approximately 350 acres and is divided into seven areas of concern. The Love Canal area is served by a public water supply system; the City of Niagara Falls water treatment plant serves 77,000 people. The site is ¼ mile north of the Niagara River.

A.37.4 Remedial Approach

The site was addressed in seven stages: initial actions and six major long-term action phases, focusing on 1) landfill containment with leachate collection, treatment, and disposal; 2) excavation and interim storage of the sewer and creek sediments; 3) final treatment and disposal of the sewer and creek sediments and other Love Canal wastes; 4) remediation of the 93rd Street School soils; 5) emergency declaration area (EDA) home maintenance and technical assistance by the Love Canal Area Revitalization Agency (LCARA), the agency implementing the Love Canal Land Use Master Plan; and, 6) buyout of homes and other properties in the EDA by LCARA.

In May 1985, USEPA began remediation of sewers, creeks, and berms by performing the following tasks:

- hydraulically cleaning sewers
- removal and disposal of the contaminated sediments
- inspecting the sewers for defects that could allow contaminants to migrate

- limiting access, dredging, and hydraulically cleaning the Black Creek culverts
- removing and storing Black and Bergholtz creeks' contaminated sediments

The state cleaned 62,000 linear feet of storm and sanitary sewers in 1986 and an additional 6,000 in 1987. In 1989, Black and Bergholtz creeks were dredged of approximately 14,000 yd^3 of sediments. Clean riprap was placed in the creek beds, and the banks were replanted with grass. Prior to final disposal, the sewer and creek sediments and other wastes (35,000 yd^3) were stored at the Occidental Niagara Falls RCRA-permitted facilities.

In October 1987, the USEPA selected a remedy to address the destruction and disposal of the dioxin contaminated sediments from the sewers and creeks: 1) construction of an on-site facility to dewater and contain the sediments; 2) construction of a separate facility to treat the dewatered contaminants through high temperature thermal destruction; 3) thermal treatment of the residuals stored at the site from the leachate treatment facility and other associated Love Canal waste materials; and, 4) on-site disposal of any nonhazardous residuals from the thermal treatment or incineration process.

A.37.5 Monitoring

In September 2008, the USEPA issued a second Five-Year Review Report that showed that the remedies implemented at the site adequately control exposures of site contaminants to human and environmental receptors to the extent necessary for the protection of human health and the environment.

RAOs/project objectives achieved? The site was deleted from the National Priorities List on September 30, 2004.

A.37.6 Costs

As part of a legal settlement, Occidental and the United States Army have agreed to reimburse the federal government's past response costs, related directly to response actions taken at the site. The primary portion of Occidental's reimbursement is $129 million. The United States Army agreed to reimburse $8 million of the Federal government's past response costs.

A.37.7 References

USEPA Superfund Information Systems, Superfund Site Information.http://cfpub-.epa.gov/supercpad/SiteProfiles/index.cfm?fuseaction=second.CleanupActs&id=0201290.

USEPA, Love Canal NPL Listing History. http://www.epa.gov-/region2/superfund/npl/0201290c.pdf.

A.38 Lower Duwamish, Cold Spring, NY

The Marathon Battery site is a former National Priorities List (NPL) site located in Cold Spring, NY. The site consists of the 70 acre former plant, 11 acres of residential properties, and sections of the Hudson River, coves, ponds, and marshland. The chemicals of concern at the site are heavy metal byproducts of battery production (primarily cadmium; also nickel and cobalt). Some dredging activities were performed in 1972-73, but significant levels of cadmium were still present in the late 1970s. Following USEPA issuing a record of decision (ROD) in 1986, a total of 189,000 tons of contaminated sediment and soils was removed from the site, treated, and disposed of off site. Additionally, natural recovery was selected for 400-plus acres of marsh and open cove area. A long term monitoring program of the site includes monitoring of groundwater, sediments, surface water, and/or biological sampling for the various sub-areas of the site. Long-term groundwater sampling results indicated that the trichloroethylene (TCE) contamination was not responding to natural attenuation as quickly as was expected. Therefore, a pilot study was initiated in 2005 to evaluate potential active remediation technologies.

In the 400-plus acres of marsh and open cove area that were selected for natural recovery, there were initial setbacks in restoring native vegetation. Site experience found that geese predation and extreme ice flow conditions hindered the process, but as of 1998 about 60% of the required 85% vegetative coverage had been established and muskrats had been observed (a good indicator). In addition, long-term groundwater sampling indicated that the TCE contamination was not responding to natural attenuation as quickly as was expected. A pilot study was conducted in February 2005 to determine the viability of enhanced reductive de-chlorination to address the TCE contamination. Initial groundwater samples indicated good potential for the technology, but a subsequent injection in October 2006 indicated that the site was not conducive to bioremediation at that time. A vapor intrusion survey was conducted in 2008 due to increasing nationwide concerns regarding vapor intrusion at residential properties located near sites with volatile organic compound contaminated groundwater. It was learned that vapor intrusion was an issue for one residential home in the properties surrounding the Marathon Battery site, and that finding resulted in the installation of a mitigation system.

A.39 Lower Fox River/Green Bay, WI

A.39.1 Summary

Environment:	Freshwater river and embayment
Scale:	Full
Contaminants of Concern:	PCBs (primary), dioxins and furans, pesticides, arsenic, lead, and mercury
Source Control Achieved Prior to Remedy Selection?	No
Final Remedy:	MNR (20 river miles - Fox River, 2650 acres - Green Bay); capping and dredging (19 river miles – Fox River; 50 acres - Green Bay)
Expected Recovery Time:	40 - >100 years (not considering that sediment remediation in upstream source areas could reduce recovery time).
MNR viewed as a success?	Not yet determined

A.39.2 Site Description

This area includes the last 39 miles of the Lower Fox River and Green Bay. Green Bay is an extension of Lake Michigan in eastern Wisconsin. The Fox River Valley is heavily urbanized and industrialized with a high concentration of paper mills. The primary sources of contamination at this site are past discharges from production and recycling of carbonless copy paper in the Fox River Valley, ongoing releases from upstream sediments.

The site has been divided into five OUs. This case study focuses on OU 2 (Lower Fox River from Appleton to Little Rapids) and OU 5 (Green Bay), which rely primarily on natural processes for remediation.

The paper industry has been active on this site since the mid-1800s. Water quality problems have been noticed since the early 1900s. PCBs found in the water and marine sediments are attributed to recycling carbonless copy paper in the Fox River Valley. Since the industrial PCB production has stopped, it has been established that 95% of the PCBs found in the water originate in the sediments. PCBs were stopped in the production of copy paper in 1971. PCB concentrations in fish have significantly decreased, particularly in the 1970s. However, since the 1980s the rate of decrease has slowed and it is unclear if PCB concentrations in fish will plateau or continue to decease.

CSM Summary: The primary natural recovery processes for this site include dispersion and physical isolation. Numerous empirical measurements were input into fate and transport models. Data from these models were then input into bioaccumulation models to predict sediment concentrations as well as ecological and human health risks for different remedial scenarios.

A.39.3 Remedial Objectives

Remediation risks for this case study include ecological and human health risks from PCBs, dioxins and furans, arsenic, lead, and mercury.

- Ecological: Significant risks to ecological receptors are present. Reproductive impairment and physical deformities have been noted in terns, cormorants, and bald eagles. This is believed to be, at least in part, due to PCB exposures.
- Human health: Unacceptable cancer and non-cancer risks were found for recreational anglers and high-intake fish consumers.

RAOs for sediments as stated in the 2002 and 2003 RODs include:

- Protect humans who consume fish from exposure to COCs that exceed protective levels.
- Minimize the downstream movement of PCBs during implementation of the remedy.

A.39.4 Remedial Approach

Final selected remedy: MNR (20 river miles - Fox River, 2650 acres - Green Bay), capping and dredging (19 river miles - Fox River, 50 acres - Green Bay).

MNR was selected as the primary remediation approach for OU 2 and OU 5. Some minor dredging will be carried out in OU 5 at the river mouth (50 acres) and in a downstream depositional area of OU 2 (8 acres).

MNR was selected for OU 2 and OU 5 because active remediation would not have produced significantly better results. Capping and dredging were not implementable in OU 2 and OU 5 due to shallow bedrock and high dispersion potential (OU 2), as well as an excessive volume of low-level contaminants in Green Bay (OU 5).

The use of MNR as the optimal remediation approach was validated through several models. Numerous empirical measurements were input into two fate and transport models including historical bathymetric surveys, sediment coring and vertical PCB profiling, sediment bed stability studies, time-trend analysis comparing direct discharges of PCBs from paper mills with steady-state releases from sediments. The fate and transport models predicted PCB concentrations in water and sediments that were then input into two bioaccumulation models calculating the contaminant transfer within the marine food web. Using these two types of models sediment concentrations as well as ecological and human health risks could be estimated for different remedial scenarios.

A.39.5 Monitoring

The RODs specify that OU 2 and OU 5 will be subject to a 40-year monitoring program. Risk reduction monitoring activities will include:

- surface water quality testing to determine downstream transport of PCB mass into Green Bay
- fish and waterfowl tissue sampling for human receptor risks
- fish, bird, and zebra mussel tissue sampling for ecological receptor risks
- possibly surface sediment chemistry analysis in MNR areas to assess potential recontamination from upstream sources
- population studies of bald eagles and double-crested cormorants for reproductive viability

The remedial design plan was scheduled to be finalized in late 2008 or early 2009.

RAO's/project objectives achieved? Baseline monitoring of PCB concentrations in MNR-designated areas was completed in 2007. The MNR remedial design plan will be finalized in 2009.

Expected recovery time: 40 to over 100 years. This time frame does not take into consideration sediment remediation in upstream source areas, which could reduce the recovery time.

Projected monitoring costs: $7,000,000 to $13,000,000

A.39.6 References

Fox River Cleanup Group, www.foxrivercleanup.com.

A.40 Manistique River, MI

A.40.1 Contacts

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A.40.2 Summary

Environment:	Tidal River and Harbor, Great Lakes area
Scale:	Full
Contaminants of Concern:	PCBs
Source Control Achieved Prior to Remedy Selection?	No; source controls were part of the final remedy.
Final Remedy:	Hydraulic dredging, cap, MNR
Expected Recovery Time:	5 years
MNR viewed as a success?	Yes; remedial construction was completed in 2000; site delisting criteria were met in Sept. 2006.

A.40.3 Site Description

The Manistique River and Harbor is adjacent to Lake Michigan in Schoolcraft County, Michigan. The primary sources of contamination at this site include release of PCBs from point sources (discharges/releases from former paper mill and lumber mill operations, discharge from area industrial facilities) and nonpoint sources (runoff from area industrial operations, combined sewer overflows, discharge from wastewater treatment plant).

The Manistique River and Harbor in Michigan was heavily contaminated by PCBs from the late 1950s onwards. Responsible parties include Manistique Paper Inc., Edison Sault Electric, Inc., and Warshawsky Brothers Iron and Metal. In 1996, the USEPA Superfund Emergency Response Team conducted a $48M hydraulic dredging program with substantial diver-assisted hand dredging, resulting in the removal of about 190,000 yd^3 of waste. The 15-acre cleanup area included a 1.7 mile area of the Manistique River and Harbor where it empties into Lake Michigan. The response action represents one of the largest PCB sediment cleanups to date by USEPA in the Great Lakes Region. USEPA conducted a long-term monitoring program to evaluate residual PCBs in cleanup area sediments.

Historical uses of Manistique River waters in the Area of Concern include receiving wastes from sawmills, a paper mill, small industries, the municipal waste water treatment plant, plus navigation for shipping, ferrying, recreational boating, and commercial fishing. Large quantities of un-decomposed sawdust remain in harbor and river sediments from the white pine lumbering era over one hundred years ago, as well as the relatively sterile sandy sediment that eroded from river banks as a result of log drives on the river. Current uses of the river and harbor include receiving the wastewater discharges from Manistique Paper, Inc. and the City of Manistique Wastewater Treatment Plant. The Manistique Wastewater Treatment Plant recently completed improvements to its system toward elimination of combined sewer overflows. Recreational uses of the river and harbor continue to be boating, sightseeing, and fishing.

From 1994 thru 2000, the USEPA Superfund Emergency Response Branch removed 190,000 yd^3 of PCB-impacted sediments from hot-spots adjacent to a former paper mill in the Manistique River and Harbor. The 15-acre remediation area, located adjacent to Lake Michigan, was dredged over a 6-year period and capped with 40-mil (0.1-inch) HDPE material anchored by 38 two-ton concrete blocks placed around the perimeter of the cap. The cap was installed to prevent erosion of contaminated sediments within a hot-spot area. Final dredging, completed in 2000, was conducted by divers with hydraulic hoses to minimize resuspension of PCBs and to ensure a clean substrate when completed. Physical inspection of the cap, conducted in 2001, one year after installation, confirmed the cap was physically intact and most anchors still in place. In 2001, confirmation sampling verified that the 10-ppm average PCB concentration goal for the Harbor and River remediation area was met. In 2004, post-remedial sampling indicated 1 ppm PCBs remaining in river and harbor sediments, exceeding the project cleanup goal of 10 ppm.

CSM summary: Remediation of PCB-contaminated sediments in river and harbor areas was achieved through a "hybrid remedy" of hotspot dredging and capping with long-term remedial performance monitoring. Additional sediment hot spots were later identified and remediated by dredging.

A.40.4 Remedial Objectives

Concerns at this site included both ecological and human health risks associated with PCBs in sediments in the Manistique River and Harbor, adjacent to Lake Michigan.

The sediment cleanup action objectives for the site focused on achieving the PCB cleanup criteria of 10 mg/Kg for River and Harbor sediments. The project RAOs were defined in the original 1987 Remedial Action Plan, the 1996 RAP update, and the 2002 RAP update. Remedial performance monitoring conducted in 2001 and 2004, as well as the Human Health and Ecological Risk Assessments completed in 2005, provided a baseline assessment for the long-term monitoring program for River and Harbor sediments. Additional sampling conducted in 2006, 2007, and 2008 demonstrated that the project cleanup goals have been exceeded.

A.40.5 Remedial Approach

Final selected remedy: A "hybrid remedy" of hot-spot dredging and capping of PCB-impacted sediments in the Manistique River and Harbor was selected to meet the 10 ppm project cleanup level, with long-term monitoring to ensure the effectiveness of the remedy.

USEPA estimated that 95% of contaminated sediments in the project area would be removed, representing 13,000 to 14,000 pounds of PCBs. Removal and capping of PCB-impacted sediments would result in a reduction of PCB levels in the harbor and river, such that within two to three years after dredging/capping activities PCB concentrations in fish are expected to drop below current health advisory levels. The total project costs for hot-spot dredging, off-site disposal of PCB-impacted sediments, and capping was estimated to be $10 million. The remedy is expected to limit the future liability of the PRPs and the community and fully restore the river and harbor to unrestricted recreational and commercial uses.

The final "hybrid remedy" addresses PCB-impacted sediment in the river and harbor through removal, source controls, and institutional controls. The final remedy was based on a project action goal of 10 ppm PCBs for river and harbor sediments. Long-term remedial performance monitoring addressed residual PCBs in river and harbor sediments.

The hybrid remedy was based on average PCB concentrations at depth of 90 ppm in the harbor and river. The bedrock harbor floor virtually guaranteed substantial residual contamination would remain. Hot-spot removal with capping was determined to isolate 95% to 99% of the PCB mass in the harbor and river basin. The 16-acre cap would reduce the sacrificial concentrations in the overall 56-acre basin to 1 ppm. Risk reduction was determined to be 97% dredge/capping versus. 65% dredging alone. The combination of hot-spot dredging and capping was determined to be the most cost effective alternative, estimated at $5.5 million (including $1.7 million for 30 years of O&M) vs. $33-43 million for dredging alone. The high degree difficulty in siting a local CDF precluded a dredging-only alternative. Remedy evaluation was based on sound science and convincing risk reduction comparisons for hot-spot removal/capping with risk reduction of 97% vs. dredging with risk reduction of 65% to meet the 10 ppm PCB action level.

Remedial alternatives were evaluated with respect to the following criteria:

- overall protectiveness
- performance
- long-term Effectiveness
- short-term risk management
- implementability
- consideration of public concerns
- restoration time-frame
- probable cost

A.40.6 Monitoring

The final Remedial Construction Completion Report was submitted in late-2001. The long-term monitoring program continues to confirm that the remedial action objective has been met of 10 ppm PCBs in river and harbor sediments.

Since 2001, long-term PCB monitoring has been conducted (in 2001, 2004, 2006, 2007, and 2008) to evaluate the effectiveness of sediment remediation to ensure the remedy remains protective of human health and the environment in the Manistique River and Harbor.

Expected recovery time: 5-10 years

Projected monitoring costs: approximately $1.5M/year

RAOs/project objectives achieved? Remedial construction was completed in 2000. The 5-year reviews have confirmed that the RAOs were initially met and continue to be exceeded. The remedy is viewed as a success. Continued study of the project area since the 1996 bathometric survey concluded that removal of old dams up-river allowed the dredged areas to be covered with a substantial thickness (3-7 ft) of clean sediment through natural depositional processes.

A.40.7 Advantages and Limitations

- Site Specific Challenges:
  - Regulatory—project schedule and winter weather delays, community acceptance, coordination with local industrial operations
  - Technical—deep excavation of sediments in tidal river, fractured bedrock bottom of river-/harbor, winter weather delays over the 6-year project period, coordination of river boat traffic and local industry operations
  - Community—concern over habitat destruction and contaminant release in river
- Acceptance: Final hybrid remedy was accepted by regulatory agency, public group, PRP group, and Great Lakes National Program Office (GLNPO) advisory group.

A.40.8 References

USEPA Manistique River Area of Concern, Lake Michigan. http://www.epa.gov-/greatlakes/aoc/manistique/index.html.

USEPA, Region 5 Superfund, Manistique Harbor & River Site Ecological Risk Assessment.http://www.epa.gov/R5Super/ecology/casestudies/manistique.htm.

Manistique Site Update, U.S. EPA Continues Dredging Activities at the Manistique River and Harbor Site. http://www.epa.gov/region5/cleanup/manistique/pdfs/manistique_fs_199808.pdf.

SMWG Review and Analysis of Selected Sediment Dredging Projects (Revised). http://clu-in.org/download/contaminantfocus/sediments/REVISED_SMWG_Review_and_Analysis_of_Selected_Sediment_Dredging_Projects.pdf.

A.41 McCormick & Baxter Creosoting Co., Stockton, CA

A.41.1 Contacts:

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A.41.2 Summary

Environment:	Marsh/wetland/floodplain
Scale:	Full
Contaminants of Concern:	Mainly PAHs and dioxin in sediments
Source Control Achieved Prior to Remedy Selection?	Yes. EPA improved site security and disposed of chemicals and sludges remaining at the site. EPA completed demolition of all site treatment vessels, structures, and above-ground tanks and piping in 1994. In 1996-1997, EPA installed a 437-foot sheet piling wall along the shoreline of Old Mormon Slough to control seepages from the former oily waste ponds, excavated approximately 12,000 yd^3 of oily waste, and backfilled the area with clean fill. The excavated material is contained on site in a lined repository in the central portion of the site. A cap was installed in the central site to prevent infiltration and to control dust migration.
Final Remedy:	Bank stabilization, capping, installation of permanent log boom for protection, relocation of occupants
MNR viewed as a success?	Yes. The installation of the stormwater collection ponds and perimeter dike, site security improvements, chemical and sludge disposal, demolition and disposal of processing equipment and site structures, construction of a sheet piling wall along Old Mormon Slough, excavation and backfilling at the oily waste pond area, installation of a cap over the most heavily contaminated central portion of the site, and installation of a sand cap in Old Mormon Slough have reduced threats to public health and the environment from these areas of the site.

A.41.3 Site Description

The McCormick & Baxter Creosoting Co. site (USEPA CAD009106527) is a 29-acre former wood-preserving facility located in an industrial area near the Port of Stockton. The site is located at 1214 West Washington Street in Stockton, CA and on the north, borders the Old Mormon Slough, which is connected to the Stockton Deepwater Channel. Except for an 8-acre portion of the site owned by Southern Pacific Railroad Company, McCormick & Baxter owns the entire property. From 1942 to 1990, McCormick & Baxter treated utility poles and railroad ties with creosote, pentachlorophenol (PCP), and compounds of arsenic, chromium, and copper. Wood treating chemicals were stored in tanks, and oily waste generated by the wood-treatment processes was stored in unlined ponds and concrete tanks on the site.

The site came to the attention of state agencies in 1977 when a fish kill in New Mormon Slough and the Stockton Deepwater Channel was attributed to a release of pentachlorophenol (PCP)-contaminated stormwater runoff from the McCormick & Baxter facility. In 1978, McCormick & Baxter constructed a perimeter dike to prevent stormwater runoff from the site and installed two stormwater collection ponds. The unlined oily waste ponds were closed in 1981. Sampling has shown that soils throughout the site and groundwater in the shallow aquifer beneath the site are contaminated with PCP, various constituents of creosote, dioxin (a contaminant in industrial-grade PCP), and metals. Soil contamination extends to greater than 40 ft below ground surface (bgs) in the central processing area of the site.

Site investigations indicate that the shallow aquifer (0 - 200 ft bgs) is connected with the deeper aquifer, which is a drinking water source. No drinking water supplies, however, are currently threatened by site-related contamination. Drinking water is a concern because approximately 105,000 people live and work within four miles of the site.

Sediment in Old Mormon Slough adjacent to the site is also contaminated, primarily with PAHs and dioxin. Site-related contaminants have been detected in fish caught in the vicinity of the site. People fish in the Stockton Channel and in Old Mormon Slough, although the McCormick & Baxter site is fenced and posted with warning signs.

A.41.4 Remedial Objectives and Approach

USEPA made changes to the sediment cleanup plan for the McCormick & Baxter Superfund Site in Stockton, California. The changes are detailed in the *Explanation of Significant Differences* (ESD). The ESD, signed in September 2005, describes the following changes to the original sediment remedy that was selected in the 1999 ROD.

- Bank Stabilization—Specific activities during the bank stabilization included clearing away concrete and debris, cutting back the slope of the bank, installing bank protection material, and building up a new berm with clean fill material. While this change increased the cost of the remedy, the result is an improvement in the long-term protection of the sand cap and thus the effectiveness of the remedy.
- Relocation—EPA can only construct the sediment cap once the vessels in Old Mormon Slough have been permanently removed. This involves relocating the owner/occupant into permanent housing away from the slough. This change adds to the total cost of the remedy but allows it to be completed without further delays.

The California Department of Toxic Substances Control (DTSC), the state support agency for the site, reviewed the ESD and concurred. USEPA and DTSC believe that the modified remedy remains protective of human health and the environment, complies with federal and state requirements that are applicable or relevant and appropriate to this remedial action, and is cost-effective.

The sediment cleanup plan selected in the ROD was the placement of a two-foot thick cap of clean sand in Old Mormon Slough, which is part of the site. The cap will isolate the contaminated sediment in the slough and eliminate the threats it poses to human health and the environment. The cap will cover about three-quarters of the slough and, after it is finished, a log boom will be installed at the outer end of the slough to prevent boat traffic from entering and damaging the cap.

Inspections conducted during the design of the cap showed that the banks along Old Mormon Slough were eroding. Tests showed that the northern shoreline was not contaminated but the southern shoreline (along the McCormick & Baxter property) was. It was necessary to reinforce the southern bank before the cap was installed. Without this reinforcement, contaminated soil could fall into the slough and recontaminate the clean sand. USEPA added bank stabilization to the remedy and divided the work into two separate phases: bank stabilization (Phase I) and construction of the cap (Phase II).

Phase I was completed in 2002, and Phase II was scheduled to begin in July 2003. However, the capping had to be delayed due to the presence of several vessels in the slough, including a large wooden barge that was being used as a residence. The vessels could not be temporarily moved out and then returned to the slough after construction, as moving them back in would damage the cap.

Because neither the owner nor USEPA could find an alternate location for the barge where it could continue to be used as a live-aboard, it became necessary to relocate the owner. People displaced from their residences by federal projects, such as the cleanup of Superfund sites, may be eligible for relocation benefits under a federal law called the Uniform Relocation Assistance and Real Property Acquisition Policies Act (URA). In this case, USEPA felt it was appropriate to assist the owner in moving to a new location.

A.41.5 Completion of Cap Construction and Monitoring

In October 2006, USEPA completed construction of a cap of clean sand over the contaminated sediment in the slough. To protect the cap, a permanent log boom was placed across the slough to prevent boat and barge traffic from damaging the cap. USEPA is currently conducting tests to determine whether the cap is intact and performing as intended. Long-term maintenance of the cap will be turned over to DTSC. USEPA and DTSC will periodically evaluate the cap to determine whether it continues to cover the contaminated sediments and meet performance standards.

A.41.6 Reference

USEPA Pacific Southwest Region 9: Superfund Website McCormick & Baxter Creosoting Co. Last updated March 2009.

A.42 Willamette River, Portland, OR

McCormick & Baxter Site, OR

A.42.1 Contacts

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A.42.2 Summary

Environment:	River
Scale:	Full
Contaminants of Concern:	PAHs, metals, creosote NAPL
Final Remedy:	Removal and amended capping

A.42.3 Site Description

The McCormick and Baxter site is located on the northeast shore of the Willamette River in north Portland. The site includes 41 acres of land and 23 acres of sediments beneath the Willamette River. The primary source of contamination at this site is the historical discharges of process wastewater directly to the Willamette River, and other process wastes were dumped in several areas of the site.

McCormick and Baxter Creosoting Company operated between 1944 and 1991, treating wood products with creosote, pentachlorophenol, and inorganic (arsenic, copper, chromium, and zinc) preservative solutions. Significant concentrations of wood-treating chemicals have been found in soil and groundwater at the site and in river sediments adjacent to the site.

A.42.4 Remedial Approach

Final selected remedy: Removal and amended capping

Construction activities during the sediment cap implementation consisted of the following major components: removal of approximately 1,630 pilings, bulkhead and dock remnants, in-water debris, a derelict barge in Willamette Cove, and other Willamette Cove features; construction of a multi-layer sediment cap using sand, organophilic clay, and armoring; monitoring well abandonment and modification; bank re-grading; and disposal and demobilization.

The sediment cap footprint encompasses approximately 23 acres and consists of a 2-foot thick layer of sand over most of the cap footprint with a 5-foot thick layer of sand over several more highly contaminated areas. Approximately 131,000 tons of sand was placed from July 7 through October 28, 2004. Within the cap footprint were areas of known NAPL migration (such as seep areas), and the cap incorporated 600 tons of bulk organophilic clay to prevent breakthrough of the NAPL through the cap. After cap placement, apparent NAPL seeps were identified in an area outside of the organophilic clay cap as a result of gas ebullition. In response to these seeps, reactive core mat containing organophilic clay were placed in these locations.

The sediment cap design incorporated different types of armoring to prevent erosion of the sand and organophilic clay layers. Articulating concrete block (ACB) mats were installed along the shore and in shallow water where erosive forces would be the greatest due to wave action. Rock armor included 6-inch-minus, 10-inch-minus, and riprap. All shallow water 10 inch-minus and ACB armoring layers were underlain with a woven geotextile fabric and 4-inch thick layer of 3-inch-minus filter rock. This fabric and rock was installed to hinder the migration of the sand through the larger and more porous armoring layer or layers.

A.42.5 Monitoring

Monitoring post cap and armoring placement identified occasional sheens around the site. Investigation showed, however, that these sheens were biological in origin and not associated with the contamination at the site (Oregon 2009). A portion of the site that included organophilic clay in the cap was also subject to significant gas ebullition. Monitoring suggested that this was coupled with reductions in organic matter content in the specific bulk organophilic clay employed in the remediation (Reible et al. 2010). Monitoring also indicated that the specific bulk organophilic clay employed in the remediation was highly variable across the site and did not exhibit the sorption capacity of other commercially available organophilic clays. Despite this, the rather conservative design with 1 ft thick layers of organophilic clay as part of the cap in the active seep areas has been sufficient to ensure that no NAPL has migrated significantly into or through the cap (Reible and Lu. 2010).

RAOs/project objectives achieved? The remediation has been successful at effectively containing the contamination at the site and current monitoring shows that the site is meeting remediation objectives (USEPA 2011).

A.42.6 References

McCormick & Baxter Superfund Site, US EPA Region 10, http://yosemite.epa.gov/r10/cleanup.nsf/sites/mccormick_baxter.

A.43 Laconia, NH

A.43.1 Summary

Environment:	Freshwater
Scale:	
Contaminants of Concern:	PAHs average of 25 ppm and max of 20,210 ppm, VOCs, TPH levels as high as 88,000 ppm
Final Remedy:	Installation of a sealed Waterloo sheet pile barrier in certain area for dry excavation. Gravity dewatered: water then filtered and disposed. Disposal of most sediment at a commercial thermal desorption facility, 20 miles from site. The rest was sent to a hazardous waste landfill 150 miles from site.

A.43.2 Site Description

The target areas for the Messer Street Manufactured Gas Plant in Laconia, NH, consisted of two one-half-acre areas in Winnipesaukee River and one three-quarter-acre area in Lake Opechee. PAHs released from coal tar discharges from a former manufacturing gas plant located adjacent to the river was the main contaminant in the target area. Results of sediment samples collected from the river indicate TPH concentration as high as 88,000 ppm in sediment from 0-2 ft and 87,000 ppm in sediment 4-6 ft. The upper 2 ft of sediment was the target of the sediment removal project, about 13,000 yd^3 of contaminated sediment was estimated to be removed.

The one-quarter mile long Winnipesaukee River connects Lake Opechee (upriver) to Lake Winnisquam (down river). The average flow velocities in the main channel of the river are very high because of the difference in water elevation between Lake Opechee and Lake Winnisquam.

The high concentration of PAHs and TPH in the target area, coupled with the high flow velocities of the river in the area makes active sediment removal (dredging and excavation) to be the preferred remedial alternative. Mechanical dredging with a Cable Arm bucket was the designated primary dredging method to remove about 40% of the contaminated sediment especially from the deep section (up to 20 ft of water) of the site. The remaining sediment was to be removed by excavation when the water levels in the lakes were lowered by up to 5 ft.

The mechanical dredging started with 2.5-y^3 Cable Arm environmental clamshell bucket, which was replaced with a similarly designed 4.0-cy bucket both of which failed to produce the desired result because they could not effectively penetrate the entire 2 ft of mostly sandy sediment. When these two bucket sizes failed, a custom built hydraulically operated 1.5-cy enclosed bucket attached to an excavator was used to complete the dredging. A crane was used to operate the Cable Arm environmental clamshell buckets and an excavator was used for the hydraulically operated enclosed bucket. A modular barge was used to convey the crane and excavator for in-river dredging. A second modular barge was used to convey the roll-offs containing dredged material from dredge sites to upland sediment handling locations. Land-based operation using dry excavation was used to remove sediment from the area that could be accessed from the land. Combined volume of sediment dredge by all the various equipment was between 12,000 to 13,000 yd^3. Following sediment removal, one foot of backfill material was placed over area where sediment was removed. About 8,250 $yd^3$of gravel and native stones was used for the backfill. Native stones were used in area of high river velocities. The same equipment used to remove sediment from each area was also use to place the back fill material in the area. The dredged areas were backfilled with gravel and native stones.

Pre-dredge and post dredge bathymetry measurements were used to determine that the targeted sediment volume has been completely removed. Post-dredge sampling was not conducted to determine the level of contaminants after the dredging. The removal contractor attributes their success in this project to the following factors: 1) availability and use of different dredge type for the in-river phase of the project and 2) working long hours and days to meet project schedules.

A.43.3 Remedial Objectives

Remove majority of contaminated sediment in 3 acres span.

Dredge depth: 2-5 ft

Contaminated sediment thickness: up to 2 ft.

Combined target removal area: 3 acres.

A.43.4 Remedial Approach

Dry and wet mechanical dredging were used at this site.

Wet and Dry dredging. Dry by installing a sealed Waterloo sheet pile barrier.

Mechanical cable arm clamshell, conventional clamshell, and hydraulic bucket used—depended on sediment type.

Silt curtain installed around the perimeter of the dredge areas. Unanticipated current surges required an extra ballast be added to hold the silt curtains in place. Sheet piling was installed along the river side of localized target areas to eliminate river flow.

A.43.5 Monitoring

Performance: In phase 1, clam shell buckets had trouble collecting sandy sediment. Three passes were required, once in Phase 1 and twice in Phase 2. Post dredging and pre dredging concentrations were significantly different. Cleanup was considered successful. All areas backfilled with mostly gravel material.

A.43.6 References

Maxymillian. Messer Street Former Manufactured Gas Plant Remediation. http://www.maxy-millian.com/portfolio/messer_street_gas_plant_remediation.html

Agency for Toxic Substances & Disease Registry as updated Apr 2010. Public Health Assessment Messer Street Manufactured Gas Plant Laconia, Belknap County, New Hampshire. May 2000. http://www.atsdr.cdc.gov/hac/pha/pha.asp?docid=1187&pg=0

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html

A.44 Metal Bank Superfund Site, Delaware River, Philadelphia, PA

Metal Bank Superfund Site, Cottman Avenue, Philadelphia PA

A.44.1 Contacts

Regulatory Contact:
USEPA Region 3, Philadelphia PA / Remedial Project Manager: Sharon Fang / 215-814-3018 /fang.sharon@epa.gov
Site Remediation Contact: Sevenson Environmental, Niagara Falls, NY

A.44.2 Summary

Environment:	Tidal River
Scale:	Full
Contaminants of Concern:	PCBs, SVOCs/PAHs/hydrocarbons, dioxins
Source Control Achieved Prior to Remedy Selection?	No; source controls were part of final remedy
Final Remedy:	Mechanical dredging/capping of source-area soils and near-shore sediments, installation of sheet pile wall, long-term monitoring
Expected Recovery Time:	100 years
MNR viewed as a success?	N/A; remedial construction completed in late-2009

A.44.3 Site Description

Primary source(s): Utility transformer oils

The Metal Bank Superfund Site is a 10-acre site located in an industrial area of northeast Philadelphia, Pennsylvania, adjacent to the Delaware River. Site operations, conducted from 1968 to 1972, included reclaiming copper parts from utility transformers and processing transformer oil for local utility companies. In 1977, USEPA determined that the site was the source of periodic PCB-impacted oil slicks in the Delaware River adjacent to the site. A U.S. Coast Guard study determined that groundwater below the site contained over 20,000 gallons of PCB-impacted oil that continuously leaked into the Delaware River. In March 2006, USEPA and the responsible parties signed a Consent Decree; the Revised Remedial Action Plan was finalized in Feb. 2008. Remedial construction was conducted at the site from July 2008 through Dec. 2009; the Remedial Action Completion Report for the site was submitted in March 2010. Over 30 years of litigation preceded final remedial action.

CSM summary: Remediation of ongoing releases of PCB impacted oils from on-site source areas into the Delaware River was achieved through both source area controls and institutional controls, with long-term remedial performance monitoring.

A.44.4 Remedial Objectives

Concerns for this case study include both ecological and human health risks associated with PCBs and hydrocarbon oils in on-site soils, groundwater, and near-shore sediments.

RAO(s)/Project objectives:

The sediment cleanup action objectives for the site focused on achieving compliance with PCB cleanup criteria of 25 mg/Kg for on-site soils and 1 mg/Kg for near-shore river sediments in the bioactive zone. The project RAOs are defined in the 2008 Revised Remedial Action Plan.

A.44.5 Remedial Approach

Final selected remedy: Excavation and capping of on-site source area soils and near-shore sediments; installation of a sheet-pile wall at the edge of the site adjacent to the Delaware River; long-term monitoring to ensure the effectiveness of the remedy.

The final remedy, implemented in July 2009, included: installation of 700 lf temporary steel sheet piling to control turbidity; mechanical dredging of 4,000 $yd^3$of PCB-impacted sediments (with shallow and deep water excavation) using an environmental clam bucket and 270-ton crawler crane (shore-based); sediment stabilization and transfer of dredged material for off-site TCSA disposal; installation of 600 lf LNAPL collection trench; placement of 60,000 ft^2Triton marine mattresses (outside the sediment excavation area) with barge-mounted crane and diver assistance; continuous turbidity monitoring with four real-time monitors; on-site soil excavation of hot-spots, site restoration with geotextile liner, 30,000 yd^3 cover soil, seeding, mulching; and long-term remedy performance monitoring. The final remedy addressed both on-site source control and off-site migration of contaminants into the adjacent waterway through source controls, institutional controls, and long-term monitoring.

Why the remedy was selected: The final remedy addresses PCB-contaminated soil, sediment, surface water, and groundwater at the site, with both source controls and institutional controls. The final remedy was based on the PCB criteria of 25 ppm for on-site soils and 1 ppm for near-shore sediments. Long-term remedial performance monitoring of on-site/down-gradient groundwater, as well as shore/near-shore sediments, addresses total PCB aroclors, as well as PCB congeners, dioxins, and SVOCs.

Remedial alternatives were evaluated for:

- Overall protectiveness
- Performance
- Long-term effectiveness
- Short-term risk management
- Implementability
- Consideration of public concerns
- Restoration time-frame
- Probable cost

Expected recovery time: 50 years

Projected monitoring costs: (TBD)

A.44.6 Monitoring

Final Remedial Construction Completion Report submitted March 2010. Long-term monitoring program underway; monitoring data not yet available.

Monitoring elements: Groundwater monitoring will be conducted to evaluate the effectiveness of the upland source removal on reducing concentrations of PCBs, dioxin, and PAHs in groundwater. Shoreline and near-sore monitoring will be conducted to evaluate concentrations of PCBs, dioxin, and PAHs in sediments to ensure the remedy remains protective of the aquatic environment in the Delaware River adjacent to the site.

RAOs/project objectives achieved? Remedial construction was completed in late-2009. The first two years of the long-term monitoring program has been completed. Overall, the remedy is viewed as a success.

A.44.7 Costs

Source removal and capping, sediment excavation and capping, waste transport and disposal, site restoration, and long-term monitoring

A.44.8 Advantages and Limitations

Site Specific Challenges:

- Regulatory—PRP litigation and bankruptcy slowed progress.
- Technical—Excavation of soil below water table, shallow/deep excavation of sediments in

tidal river, expedited construction schedule, weather delays.
- Community—Concern over habitat destruction and contaminant release in river.

Acceptance: Final remedy was accepted by public and PRP group.

A.44.9 References

USEPA, Mid-Atlantic Superfund, Metal Bank. http://www.epa.gov-/reg3hwmd/super/sites/PAD046557096/index.htm

A.45 Missoula County, MT

Milltown Reservoir Sediments Operable Unit, Missoula County, MT (CERCLIS ID #MTD980717565)

A.45.1 Contacts

Diana Hammer, USEPA (Region 8, Lead Agency), 406-457-5040, hammer.diana@epa.gov
Keith Large, MT DEQ (Supporting Agency), 406-841-5039, klarge@mt.gov

A.45.2 Summary

Environment:	Freshwater reservoir
Scale:	Full
Contaminants of Concern:	Groundwater: arsenic, cadmium, copper, lead, zinc, and mercury Surface water: arsenic, cadmium, copper, lead, and zinc
Source Control Achieved Prior to Remedy Selection?	No
Final Remedy:	Sediment removal (approximately 2.2 million yd^3) and MNR (approximately 540 acres)
Expected Recovery Time:	4-10 years beginning in 2011
MNR viewed as a success?	Yet to be determined

A.45.3 Site Description

Primary source(s): For nearly one-hundred years, mine wastes were discharged into the headwaters of the Clark Fork River and after 1908, came to rest behind the Milltown Dam. In the same year, the largest flood on record in the area washed the mining waste into the Milltown Reservoir, creating approximately 6.6 million yd^3 of contaminated reservoir sediments.

Location: The Milltown Reservoir Sediments Operable Unit (MRSOU) is one of three operable units, which also includes the Clark Fork River and Milltown Water Supply, near Milltown, Montana. The MRSOU covers approximately 540 acres (as defined by the area inundated by the maximum pool elevation of 3,263.5 ft).

Beginning in the 1860s, mine wastes were discharged to the headwaters of the Clark Fork River. In 1908, the Milltown Dam was constructed. In the same year, mine waste that had accumulated behind the dam was flushed into the Milltown Reservoir by a large flood. From here, the mine waste contaminated the local drinking water source.

In September 1983, the Milltown Reservoir was added to the National Priorities List (NPL). A year later, the city of Milltown installed a new water system. Remediation studies and investigations dominated activity at the site into the 2000s. The EPA issued a ROD in December 2004. It stressed a 3-R approach: remediation, restoration, and redevelopment. In August 2005, a Consent Decree identifying Atlantic Richfield Company and NorthWestern Corporation as the site's responsible parties, was signed.

In the fall of 2006, remediation of the Superfund site began. Concurrent restoration of the site began in 2008. In 2009, sediment removal from the Milltown Reservoir was completed. By February 2010, the Milltown dam had been removed. Remediation action construction activities are ongoing and are expected to be completed in the near future (approximately a year).

CSM summary: The primary source of COCs in the Milltown Reservoir is contaminated sediment. Secondary sources of COCs are exposed aquatic flora and fauna, surface water, and suspended sediment transported from the Clark Fork River.

A.45.4 Remedial Objectives

The MRSOU poses risks to human health via ingestion of contaminated potable groundwater and ingestion of aquatic life. Risks exist for flora and fauna directly and indirectly exposed to COCs.

RAOs/Project objectives: Remediation of the MRSOU is twofold: (1) reduction or elimination of the groundwater arsenic plume and (2) risk reduction to aquatic life. RAO's exist for groundwater and surface water at the site.

The groundwater RAOs, as reported in the site's ROD, are as follows:

- Return contaminated groundwater in the Milltown alluvial aquifer to its beneficial use within a reasonable time frame.
- Comply with State and Federal groundwater standards, including nondegradation standards, for arsenic, cadmium, copper, lead, mercury, and zinc.
- Prevent groundwater discharge containing arsenic and metals that would degrade surface waters.

Temporary and long-term surface water RAOs were developed for the MRSOU. The temporary RAOs waive ambient surface water standards for cadmium, copper, zinc, lead, arsenic, iron, and total suspended solids during the construction phase. The long-term surface water RAOs, as reported in the site's ROD, are as follows:

- Achieve compliance with surface water standards, unless a waiver is justified.
- Prevent ingestion of or direct contact with water posing an unacceptable human health risk.
- Achieve acute and chronic Federal Ambient Water Quality Criteria for arsenic, cadmium, copper, lead and zinc.

Additionally, performance standards exist for 1) the protection of waste left in place and local repositories, 2) the new channel, and 3) re-vegetation of river banks and the flood plain. Notably, the site will be redeveloped as a state park.

A.45.5 Remedial Approach

Final selected remedy: Remedy alternative 7A2, modified: partial dam removal with partial sediment removal of the Lower Reservoir plus Groundwater ICs and natural attenuation within the aquifer plume.

Remedy Selected alternative 7A2, modified consists of many phases. The major remedial elements, as reported in the ROD, are as follows:

- Water in the Milltown Reservoir was drained and a bypass channel for the Clark Fork River was constructed.
- Approximately 2.2 million yd^3 of contaminated sediment (with the greatest pore water contaminant concentrations and significant potential to cause future surface water degradation) was removed from the Reservoir.
- A railroad was built specifically to transport this sediment to a lined solid waste disposal facility less than one mile away.
- The Milltown Dam was removed.
- The replacement water supply program and implementation of temporary groundwater institutional controls will continue until the Milltown aquifer recovers using monitored natural recovery.
- Long-term operation and maintenance will be conducted.

Advantages of the selected remedy:

Remedy alternative 7A2, modified was selected for the following reasons:

- Permanent, long-term protection of public health and the environment
- Recovery of the Milltown drinking water supply
- Use of existing waste management areas for waste disposal
- Substantial elimination of contaminant release from ice-scouring and catastrophic events
- Return of the Clark Fork to a free flowing state, enabling unrestricted fish passage
- Redevelopment possibilities, including a recreational fishery

Disadvantages of the selected remedy:

The following limitations or disadvantages exist for remedy alternative 7A2, modified:

- Reservoir drawdown and remedy construction could negatively impact downstream aquatic life in the short-term
- The remedy is complex
- The remedy is expensive

Expected recovery time: The selected remedy will allow recovery of the Milltown/Bonner aquifer within 4-10 years.

A.45.6 Monitoring

Monitoring elements: In addition to monitoring that occurred during the remedial action, O&M activities will take place for at least five years after construction has been completed in order to ensure that performance standards are being met.

The Statement of Work for Milltown Reservoir requires that a long-term monitoring plan be developed at least 60 days prior to the completion of remediation action construction activities. Such a plan has not yet been written.

RAOs/project objectives achieved: The success of MNR at the MRSOU is yet to be determined.

A.45.7 Costs

Projected monitoring costs: N/A

Net present value for project costs: $106,000,000 (discounted by 3% per year for the estimated life of the project)

A.45.8 References

USEPA. Integrating the “3 Rs”: Remediation, Restoration and Redevelopment, the Milltown Reservoir Sediment Site and Missoula County, Montana. April 2011. Available at www.epa.gov/region8/superfund/mt/milltown/2011ReadyForReuseFactSheet.pdf.

USEPA. Record of Decision: Milltown Reservoir Sediments Operable Unit of the Milltown Reservoir/Clark Fork River Superfund Site. December 2004. Available at www.epa.gov-/region8/superfund/mt/milltown/mrsrod.html.

USEPA. Superfund Program Record of Decision Factsheet: Milltown Reservoir Sediments Operable Unit of the Milltown Reservoir/Clark Fork River Superfund Site. No date. Available at www.epa.gov/region8/superfund/mt/milltown/pdf/mrsRODfs.pdf..

Envirocon. Repository Operation and Monitoring Plan, Milltown Reservoir Sediments Operable Unit, Final. February 3, 2010.

A.46 Money Point, VA

A.46.1 Summary

Environment:	Marine
Scale:	
Contaminants of Concern:	PAH: 100 ppm, PCP, dioxins, arsenic, chromium, copper, lead, zinc, creosote as a free product found in sediments
Final Remedy:	Mechanical dredging (clamshell/bucket dredge) using silt curtains down to bottom and absorbency booms at surface; barge/crane operated within containment area. Contaminated sediment will be shipped by barge to Port Weanack on the James River. There it will be unloaded and trucked for disposal at either Charles City landfill (two-thirds of the material) or Pungo (one-third of the material) for thermal treatment. On-site disposal of some dredged sediment.

A.46.2 Site Description

Year: 2009-present

Target Volume: 80,800 yd^3

A.46.3 Remedial Objectives

Cancer in mummichogs reduced to background levels: to be fishable by 2020.

Contaminated sediment area:

- Phase 1: 7 acres including wetlands and forested shoreline
- Phase 2: 12 acres in 2012

Contaminated sediment thickness:

- Phase 1: 1 foot
- Phase 2: up to 6 ft

A.46.4 Remedial Approach

Earth moving equipment and a clamshell/bucket dredge were used for excavation.

A.46.5 Monitoring

Use of silt curtains down to bottom and absorbency booms at surface; barge/crane operated within containment. Silt curtains were placed at the top and bottom of the work areas.

Performance: Mummichog tissue sampled for cancer every 1-2 years; until cancer reduced to background levels.

- Currently work in progress.
- Dredged areas are backfilled with clean sand and topsoil.
- Petroleum sheen releases from sediment disturbances.

A.46.6 References

Money Point Cleanup Fact Sheet. http://www.elizabethriver.org/PDFs/MoneyPoint/Money-Point-Cleanup-Fact-Sheet.pdf.

USEPA. Mid-Atlantic Superfund Atlantic Wood Industries, Inc. Record of Decision December 2007 as updated Feb 2012. http://www.epa.gov-/reg3hwmd/npl/VAD990710410/rod/rod2007.htm.

USEPA. Record of Decision Operable Units 1, 2, & 3. 2007. http://www.epa.gov-/reg3hwmd/npl/VAD990710410/rod/AWI_2007_ROD-Part_I_Declaration_and_Table_of_Contents_List_of_Acronyms.PDF.

A.47 Natural Gas Compressor Station, MS

A.47.1 Summary

Environment:	Freshwater
Scale:	Full
Contaminants of Concern:	PCBs
Final Remedy:	Creek flow diverted by pumping to nearby tributary to allow for dry excavation. Little to no dewatering of excavated material done. Typically dry enough to put into vehicles to transport to Emelle, AL. In a few instances, fly ash or lime was mixed in to make the material dry enough for transport.

A.47.2 Site Description

Year: 1997

Contaminated sediment area: 2 mile stretch on the Little Conehoma Creek approximately, 15-25 ft wide.

Water Depth: Creek bed/flood plains

Target Volume:

51,432 yd^3 of stream sediment

8,290 yd^3 of floodplain soils.

Actual Volume Removed: 23,883 yd^3 excavated

A.47.3 Remedial Objectives

1ppm PCB for Creek, 5ppm > for floodplain soils.

Sediment thickness: At one point, excavation to depths of 8-10 ft necessary to reach cleanup levels. Remainder were 0-8 ft.

Dredge depth: Avg. 1 ft, more near outfall.

A.47.4 Remedial Approach

Dry excavation (Caterpillar 320 and long stick excavator)

A.47.5 Monitoring

There were no suspension controls because dry excavation was used. Air monitoring was in effect.

All remediated areas were at or below 1 ppm. All goals were met.

A minimum of 2 ft of clean backfill was installed along the banks of section 26. Backfill was followed by seeding and application of mulch.

A.47.6 References

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.48 New Bedford, MA 1995

A.48.1 Summary

Contaminants of Concern:	Six hotspots exhibiting: PCBs: 4,000-200,000 ppm Metals: 0-4,000 ppm Metals are not targeted because they are co-located with PCBs.
Final Remedy:	Hydraulic cutterhead dredge. Dredged material transported by pipeline one mile to a temporary CDF. The contaminants were later dewatered and disposed at an off-site TSCA-permitted landfill.

A.48.2 Site Description

Year: 1995

Target Volume: 10,000 yd^3

Actual Volume Removed: 14,000 yd^3

A.48.3 Remedial Objectives

EPA calculated that by targeting 4,000 ppm, greatest percentage of PCB mass could be removed with least volume of sediment.

Contaminated sediment area: 5 acres

A.48.4 Remedial Approach

Hydraulic cutter head dredge

Dredge depth: 0–4 ft

Oil was trapped throughout the hotspot, so a shroud was put over the cutter head to catch the oil as it was released.

The use of silt curtains was abandoned because they appeared to be contributing to oil problems by continuous disturbance of the bottom in the varying tidal and weather conditions. High suction rate and slow auger rotation were emphasized to control resuspension.

A.48.5 Monitoring

Performance: Goal was met. Post dredging sampling showed the five acre area to be well below the 4,000 ppm PCB goal.

A.48.6 References

USEPA Superfund Record of Decision Amendment: New Bedford EPA ID: MAD9807313335. Apr 1999. http://www.epa.gov/region1/superfund/sites/newbedford/9721.pdf.

USEPA. First Five-Year Review Report for the New Bedford Harbor Superfund Site. SDMS DocID 237034. Sep 2005. http://www.epa.gov/superfund/sites/fiveyear/f05-01005.pdf.

USEPA. Second Five-Year Review Report for the New Bedford Harbor Superfund Site. SDMS DocID 470549. Sept 2010. http://www.epa.gov-/region1/superfund/sites/newbedford/470549.pdf.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.49 New Bedford, MA 2004

A.49.1 Summary

Environment:	Harbor
Scale:	
Contaminants of Concern:	PCBs Lower harbor: 100ppm. Upper Harbor: 50,000 ppm.
Final Remedy:	Two hydraulic cutterheads were used. A 5-acre dewatering facility was created on site for dredged sediments. 4 CDFs were created near shore. Once most of the water has been eliminated from the slurry, it is then sent off site to a TSCA disposal facility in Michigan via rail or truck.

A.49.2 Site Description

The New Bedford Harbor Superfund site is located in Bristol County, Massachusetts (USEPA 2010; USACE 2005). PCB levels in the upper harbor sediments currently range from below detection to greater than 10,000 ppm. PCB levels in the lower harbor sediments range from below detection to approximately 1,000 ppm. Sediment PCB levels in the outer harbor are generally lower. Operable Unit 1 covers the upper and lower harbor, with a 1998 Record of Decision (ROD) that selected dredging of sediment above cleanup goals below:

- Upper harbor subtidal and mudflat areas: 10 ppm PCBs
- Lower harbor subtidal and mudflat areas: 50 ppm PCBs

The OU 1 ROD has been modified by three Explanations of Significant Differences (ESDs) in 2001, 2002, and 2010. Based upon additional sampling conducted since the original ROD, the estimated of quantities of material requiring dredging and disposal has increased 95 percent to approximately 900,000 cy3. The OU 1 remedy now, includes removal of roughly 900,000 cy3 (approximately 260 acres) of PCB-contaminated sediment, and disposal of this sediment both off site and in 3 shoreline CDFs in the upper harbor.

Operable Unit 2 addressed the hot spot sediments covering a 5-acre area near the Aerovox mill defined by PCB levels above 4,000 ppm. The hot spot ROD was issued in 1990, an amended ROD in 1999, and the hot spot remedy was completed in 2000. All OU 2-contaminated sediments were disposed of in a licensed off-site disposal facility.

Hydraulic dredging with a rotary auger has been conducted in the harbor for several years. Hydraulic dredging was selected at this site because (Gaynor et al., 2010):

- It was believed to be more cost efficient than mechanical dredging for high sediment volumes.
- It was capable of drawing 18–30 inches of water, which facilitates dredging within shallower intertidal areas.
- It is an efficient method of pumping sediment to central, but distant onshore handling facilities.
- It was expected to provide uniform removal of material at predetermined cut depths.

The pump on each dredge delivers 1,500–3,000 gallons per minute (gpm) of slurry with a solids content of up to 20 percent. Two dredges operating by turn in two different tidal zones provide a constant flow of dredged material for the dewatering systems downstream to operate uninterrupted.

Year: 2004-present

Lower harbor ranges from: 6-12 ft

Shipping channel: 30–50 ft

Sediment is silty sand.

Upper harbor near the bridge

Width: 250 ft

Depth: 2–6 ft

Under the bridge

Width: 110 ft

Depth: 18 ft

Target Volume: Not available

Initial ROD, Upper Harbor: 433,000 yd^3, Lower Harbor: 17,000 yd^3, amendment: Total: 867,000 yd3

A.49.3 Remedial Objectives

Goals for area average basis:

Upper harbor: 10 ppm PCB

Lower harbor: 50 ppm PCB

Intertidal areas with residential: 1 ppm PCB

Intertidal areas with public access: 25 ppm PCB

Salt marsh areas with no access: 50 ppm

Contaminated sediment area: 170–190 acres

A.49.4 Remedial Approach

Two hydraulic cutter head dredges—one for each tide. Verification sediment samples after dredging. Initiation of long-term local seafood sampling program to track PCB levels in seafood. Periodic water quality monitoring following dredging.

A.49.5 Monitoring

Silt curtains abandoned. Best management practices reduced turbidity impacts due to sediment scour from workboats, prop-wash, and pipeline groundings, and turbidity caused by silt curtains when in contact with sediment during low tide in shallow water. PCB and toxicity data, along with in situ water quality measurements, confirm that dredging is ecologically protective, while allowing remediation efforts to progress.

Performance:

Dredging is still in progress. There is still 700,000+ yd^3 to be dredged. Each year an average of 20,000 yd^3 of sediment is removed and disposed.

Residuals:

2009 PCB levels in top 2cm of sediment:

Upper harbor: 75 ppm

Lower harbor: 5.1 ppm

A.49.6 References

EPA Superfund Record of Decision: New Bedford EPA ID: MAD980731335. Sep 1998. http://www.mass.gov/eea/docs/eea/oceans/serth/p1002bmf.pdf.

USEPA Superfund Explanation of Significant Differences: New Bedford EPA ID: MAD980731335. Aug. 2002. http://www.epa.gov-/superfund/sites/rods/fulltext/e0102019.pdf.

USEPA. First Five-Year Review Report for the New Bedford Harbor Superfund Site. SDMS DocID 237034. Sep 2005. http://www.epa.gov/superfund/sites/fiveyear/f05-01005.pdf.

USEPA. Second Five-Year Review Report for the New Bedford Harbor Superfund Site. SDMS DocID 470549. Sep 2010. http://www.epa.gov-/region1/superfund/sites/newbedford/470549.pdf.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.50 Newport, DE

A.50.1 Contacts

Regulatory Contact: US EPA (Region III)
EPA ID# DED980555122
Site Contact: Anthony Iacobone

A.50.2 Summary

Environment:	Tidal and non-tidal freshwater wetlands and the Christina River
Scale:	Full
Contaminants of Concern:	Cadmium, lead, and zinc (drivers for remedy)
Source Control Achieved Prior to Remedy Selection?	No
Final Remedy:	Capping, wetland remediation, restoration and monitoring, waste consolidation, excavation, sediment disposal, and dredging
MNR viewed as a success?	Not applicable

A.50.3 Site Description

The E.I. du Pont de Nemours & Co. Inc., (Newport Pigment Plant Landfill) Superfund Site (a.k.a. DuPont-Newport Site) is located in the Town of Newport, New Castle County, Delaware (Figure 1). It is an approximately 120-acre site that includes the location of a paint pigment production facility (Ciba Specialty Chemicals or CibaSC), a former chromium dioxide production facility (DuPont

Holly Run), two industrial landfills (the north and south landfills) separated by the Christina River and baseball diamond owned by DuPont situated just northwest of the paint pigment plant across an Amtrak railroad. The site also includes portions of the Christina River.

Sediment impacts, and in some cases surface water impacts, at the site were a result of the following: 1) precipitation of some groundwater contaminants as they discharged to the Christina River or wetlands; 2) direct dumping including breached dikes at one of two landfills located on the south side of the site; 3) erosion/surface water runoff which in all likelihood carried contamination from a northern disposal area to the Christina River during the time the landfill was operational; and 4) incoming tides carrying contamination from the northern wetlands. Sediment samples were collected from wetlands located on the north side of the site (including a drainage way) and the south side of the site (including a south pond), and the Christina River.

Sediment contaminants included arsenic, barium, cadmium, chromium, copper, lead, mercury, and zinc. Additionally, groundwater seeps to surface water included aluminum, cadmium, chromium, copper, iron, lead, mercury, zinc, 1,2-dichlorobenzene, chlorobenzene, 1,4-dichlorobenzene, tetrachloroethene, and trichloroethene.

Tidal wetlands exist at the site on both sides of the Christina River adjacent to the landfills. The northeast corridor of the Amtrak Railroad runs along the northern edge of the site, and a junk yard exists immediately to the southwest of the site.

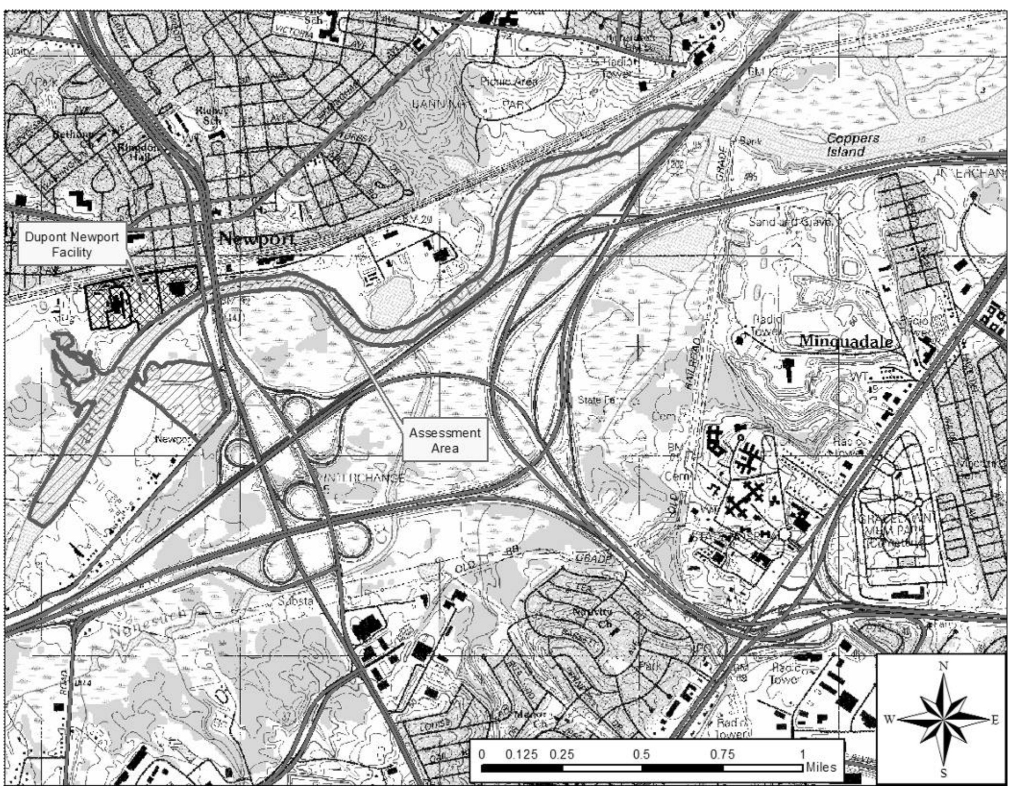


Figure 1. Site location map.

Currently, CibaSC operates a paint pigment plant at the site and DuPont operates a groundwater pretreatment plant. Two landfills serve as long-term containment of waste, and restored wetlands provide ecological habitat.

The DuPont- Newport site, was originally built during the period of 1900 to 1902. The plant was owned and operated by Henrik J. Krebs and manufactured Lithopone, a white, zinc- and barium-based inorganic paint pigment. In 1929, DuPont purchased the plant and continued to produce Lithopone. Lithopone production ceased in 1952 because of reduced demand for the product. DuPont had begun to produce different organic and inorganic pigments by this time along with other miscellaneous products at the site, including purified titanium metal, blue and green copper phthalocyanine pigments, red quinacridone pigment, high purity silicon, thoriated nickel and chromium dioxide.

During the 1970’s DuPont expanded its chromium dioxide production operation by building the DuPont Holly Run plant. In 1984, the pigment manufacturing operations were sold to Ciba-Geigy Corporation (now CibaSC), but retained the chromium dioxide production operations. From 2000 to 2001, DuPont shut down the Holly Run plant and dismantled most of it.

The former DuPont Holly Run plant and the CibaSC plant were built on fill material placed over low-lying farmland. Most of the fill material underneath the CibaSC plant, and a small portion of the former DuPont plant, is contaminated with heavy metals such as cadmium, lead, barium, and zinc as a result of past disposal operations and poor raw material storage and handling practices. Waste and off-specification products were disposed of in the north and south landfills prior to CibaSC ownership.

The north landfill was constructed by disposing miscellaneous fill behind an artificial berm along the Christina River. Wastes, including Lithopone, other organic pigments, chromium, and miscellaneous materials such as thoriated nickel were disposed of in the north landfill from 1902 to 1974. The maximum waste depth in the landfill was approximately 20 to 25 ft with no bottom-liner system constructed prior to fill placement. Drums containing thorium-232/nickel alloy and processing materials were disposed in this area from 1961 to 1966 and are buried about 10 ft below the top surface of waste fill. Fill included trash, steel drums, concrete rubble, steelwork, and artificial marble. Waste from the landfill migrated into the adjacent wetlands and the Christina River.

The south landfill was used for the disposal of large quantities of Lithopone wastes, which were pumped through a pipe on the river bottom and discharged to a diked area in a wetland. The bottom of the south landfill is also unlined and some of the waste is currently in the water table. The south landfill operated from approximately 1902 to 1953.

During the late 1970’s and early 1980s’ groundwater was sampled from on-site monitoring wells. The results indicated elevated levels of heavy metals and volatile organic compounds (mainly tetrechloroethene and trichloroethene) in groundwater. During August 1988, DuPont entered an ACO with the EPA and agreed to perform an RI/FS for the site. This study included collection of groundwater, soil, sediment, and surface water (both river and wetlands) samples. Although the site was originally included on the NPL because of groundwater contamination caused by the north landfill, the RI/FS found that the Christina River and the adjacent wetlands were contaminated as well. Some areas showed significant impacts to the ecosystem, although other areas had only minor impacts. The site was added to the NPL list in February 1990 and a ROD was issued in August 1993.

In 1994, DuPont submitted a Remedial Design/Remedial Action Work Plan, as directed by the ROD and the ACO. Incorporated in this work plan was an initial value-engineering assessment that identified the most cost-effective implementation of remedies specified in the ROD that are also protective of human health and the environment. Pre-design investigations were outlined for the north and south wetland areas and the Christina River to delineate areas for sediment removal. A phased sampling strategy was developed and implemented to fulfill the ROD requirements. The ROD required delineation of three metals (cadmium, lead, and zinc) that were associated with the pigment manufacturing at Newport. Two sets of criteria were provided in the ROD: EPA site-specific sediment cleanup criteria (SSCC) and apparent effects threshold values (AETs). Sediment concentrations exceeding the SSCC in the sediments would need to be excavated while sediment concentrations below the AET values could be left in place. Those concentrations detected between these two criteria may have required additional investigation.

CSM summary: As part of the RI/FS, EPA conducted a human health risk assessment and an environmental risk assessment. Most of the risks at the site were to environmental receptors, especially aquatic life. The environmental risk assessment determined that several areas of the north and south wetlands and the Christina River warranted remediation based on the review of all available data, most importantly, that of sediment toxicity tests, benthic studies, and sediment bulk chemistry data.

A.50.4 Remedial Objectives

Based on the potential impact to human health and the environment, the EPA determined that the following areas of the site warranted remediation:

1. North landfill including the drainage way: This area continually released contaminants to the groundwater in the fill and/or Columbia aquifers, which affected ground-water discharge areas. One of the areas affected by the discharge was the Christina River which had exceedances of AWQC or state water quality standards or state water quality standards (State WQS) exceedances and sediment, which exhibited unacceptable environmental impacts. The north drainage way, which also received discharges, exhibited extreme impacts to ecological receptors. However, EPA determined that treatment of the contaminated sediments in the north drainage way, due to site-specific conditions, was not feasible. EPA determined that both engineering and institutional controls at the north landfill and associated wetlands would be protective enough for human health and the environment.
2. South landfill and associated wetlands: This area continually released contaminants to the groundwater in the fill zone and/or Columbia aquifers, which affected groundwater discharge areas. The two discharge points were the river and the south wetlands, which had

AWQC and State WQS exceedances and sediment which exhibited unacceptable environmental impacts. Future subsurface maintenance or construction activities would have resulted in unacceptable risk to humans. Part of the wetland area exhibited unacceptable environmental impacts including low benthic density and poor benthic diversity (a high percentage of pollution tolerant species).

3. Christina River: Some of the sediments in the river exhibited unacceptable environmental impacts. Additionally, AWQS and State WQSs for several site-related contaminants, including cadmium, lead, and zinc were exceeded in the vicinity of the site.
4. CibaSC plant and small portion of the DuPont holly Run plant: Exposure to surface and subsurface soils caused unacceptable risks to humans. This area continually releases contaminants to the groundwater in the fill zone and/or Columbia aquifers, which affects groundwater discharge areas. One of the discharge points affected is the Christina River which had AWQC or State WQS exceedances and sediment which exhibited unacceptable environmental impacts.

The remedial alternatives in ROD addressed contaminated soils, sediments, surface water, and groundwater at the site. The RAOs specific to sediment included the following:

1. Prevent exposure to contaminated sediments.
2. Prevent exposure to highly contaminated surface water.
3. Prevent further degradation of the environment caused by the discharge of contaminated groundwater to the Christina River and to the wetlands adjacent to the north and south landfill.

A.50.5 Remedial Approach

Delineation investigation, remedial action, and restoration of the wetlands and river areas were completed sequentially. The pre-design investigations for the wetlands were completed before the river. Remedial action and restoration was completed for the North Wetlands, followed by the South Wetlands, and then the Christina River. The actions are summarized below.

A.50.5.1 North Landfill and Associated Wetlands

Final selected remedy: Capping; wetland remediation, restoration and monitoring; vertical barrier wall down to base of the Columbia aquifer; and groundwater recovery and treatment.

The north landfill cleanup activities included the capping of 7.6 acres of the north landfill and installing a groundwater barrier wall of 1,730 ft in length along the side of the landfill adjacent to the north wetlands and the Christina River. Sediments were excavated from the north wetlands and north drainage area and disposed of in the north landfill prior to capping. Cleanup activities in the north wetlands included the excavation of sediments from the north wetlands (including the north drainage way) that were contaminated with heavy metals, on-site disposal of the sediments in a newly constructed cell in the north landfill, and restoration of the north wetlands.

The selected remedy for the north wetlands was modified during the remedial design in several ways that greatly enhanced the cleanup. As a result of DuPont's desire to construct the best possible wetland, EPA, DNREC, and DuPont collaborated on design changes that brought about the improvements. As presented in DuPont Environmental Remediation Services 1997a, the North Wetlands remediation and restoration consisted of the following basic components that were not part of the ROD requirements:

- stabilization of the river berm
- shoreline erosion protection
- sediment excavation to a greater depth and backfilling
- construction of a water control structure
- sediment stabilization with erosion matting
- phragmites control program

In total for the north wetlands, DuPont remediated 2.7 acres of wetlands and excavated 9,500 yd^3 of contaminated soil.

Sediment criteria were as follows: cadmium – 9.6 mg/kg, lead – 660 mg/kg, and zinc – 1,600 mg/kg. These concentrations were to be protective of human recreational exposure.

Why the remedy was selected: Prevent continued releases of contaminants to groundwater which discharges to the river and the north wetlands; cleanup areas of unacceptable environmental impact in the north wetlands; prevent exposure of plant and terrestrial life to contaminated soils.

Stabilizing the river berm and providing shoreline bank erosion protection improved the drainage way habitat, stabilized sediment, increased the amount of open water at high tide, improved water quality, and provided better forage and cover for fish and wildlife. More importantly, river berm stabilization ensured long-term wetlands protection and prevented the loss of the berm and the wetlands.

For excavation, the ROD required removing 1 ft of sediment from the wetlands. DuPont removed all sediment down to the marsh clay deposit layer (approximately 2 to 3 ft) to eliminate any potential future concerns of recontamination from sediments left in place. Removal of the additional material, in conjunction with the water control structure, allowed for a permanent pool of water to be a part of the final design. In addition, the design allowed the wetland to be inundated daily during high tide. Thus, this design creates a clean, permanent open water habitat that was not previously present.

The Phragmites eradication program consisted of spraying and burning, and physical destruction of the root mass. Increased saline circulation in the marsh was done to exclude future invasion by Phragmites. Control of Phragmites and other invasive species helped promote colonization of the marsh habitat by a more diverse assemblage of native plants. A diverse plant assemblage provides for better animal forage and enhances the functional capacity of the restored marsh to support wildlife.

The restoration enhancements included a significant reduction of the site-specific sediment cleanup criteria for the north wetlands, excavating deeper heavily contaminated sediments that were discovered during remedial design, and increasing the biodiversity of the wetland. The performance standards of the ROD had to be modified in order to accomplish these changes.

Figure 2. North Wetland - Pre-remediation.

Figure 3. North Wetland - Post-remediation.

A.50.5.2 South Landfill Area and South Wetlands

Final selected remedy: Excavation, restoration and monitoring

The South Wetlands remediation and restoration were similar to that of the North Wetlands in that DuPont proactively included the following basic components that were above and beyond the ROD requirements in an attempt to optimize functions and values that could be provided by the restoration site (DuPont Environmental Remediation Services, 1997b):

- sediment excavation to a greater depth and backfilling
- hummock construction and planting
- sediment stabilization with erosion matting
- removal of berm
- South Pond enhancement
- phragmites control program

The remedy for the south wetland was modified during remedial design to enhance the cleanup based on DuPont's desire to construct the best possible wetland. The enhancements included a significant reduction on the site-specific sediment cleanup criteria for the south wetlands, excavating deeper, heavily contaminated sediments that were discovered in the remedial design, increasing the biodiversity of the wetland, and removal of the berm (mentioned above). The performance standards for the ROD were modified to accomplish these changes. During the remediation of the South Wetlands, portions of the berm up to 11 ft in depth were removed to create hummocks. Berm removal resulted in the opportunity to open the South Pond to tidal influence. The South Pond did not require remediation; however, 2 ft were excavated to remove fine-grained sediments. It also was re-contoured to provide a more gradual intertidal zone that was vegetated with emergent vegetation forms. Drainage features were added to facilitate sufficient water storage between high-tide cycles and develop more direct access to improve the tidal exchange throughout the South Wetlands. Tidal habitat was significantly improved by the removal of additional materials from the wetlands, berm, and South Pond areas, in conjunction with the enhancement of drainage features.

The south landfill cleanup plan included a barrier system to physically separate the waste material from the environment. The barrier system included a slurry wall that was placed parallel with the Christina River. In addition, the south landfill was capped using a geosynthetic clay liner and a high density polyethylene membrane. The membrane cap extended down the riverbank to the low mean tideline. The riverbank was then covered with armor stone. Sediment samples were collected in the Christina River along the south landfill to serve as a baseline for future monitoring to ensure that heavy metals from the south landfill do not contaminate the river sediments.

A total of 37,000 yd^3 of contaminated sediments were removed from a 6.5 acre wetland and pond area. The wetlands were rebuilt/restored and an additional 1.7 acres of wetlands were created by removing 20,000 yd^3 of contaminated soil from a berm. Approximately 57,000 yd^3 of material were disposed of in the south landfill.

Sediment criteria were as follows: cadmium – 35 mg/kg, lead – 670 mg/kg, and zinc – 2,000 mg/kg. These concentrations were to be protective of human recreational exposures

Why the remedy was selected: Prevent unacceptable impacts to environmental receptors.

As with the North Wetlands, DuPont exceeded the 1-foot sediment removal depth required by the ROD and removed all sediment down to the marsh clay deposit layer (approximately 2 ft) to eliminate any potential future concerns of recontamination from sediments left in place. Portions of the berm, up to 11 ft in depth, were removed to create hummocks. The creation of the hummocks increased cover type diversity and vertical stratification of the wetlands.

Erosion matting increased sediment stabilization and proved effective during severe storm events. The matting also facilitated the development of a substrate for colonization by benthic invertebrate fauna and vegetation.

Removal of the berm resulted in the opportunity to open the South Pond to tidal influence. The South Pond did not require remediation; however, it was excavated 2 ft to remove fine-grained sediments. It was also re-contoured to provide a more gradual intertidal zone that was vegetated with emergent vegetation. Drainage features were also added to facilitate sufficient water storage between high-tide cycles and develop more of a direct access to improve the tidal exchange throughout the South Wetlands.

Control of Phragmites and other invasive species helped promote colonization of the marsh habitat by a more diverse assemblage of native plants. A diverse plant assemblage provides for better animal forage and enhances the functional capacity of the restored marsh to support wildlife.

Removal of the additional materials from the wetlands, berm, and South Pond areas, in conjunction with the enhancement of drainage features, allowed for a significantly improved tidal habitat than previously was present. The increased tidal water storage and the daily inundation of the wetlands at high tide and the water exchange in the South Pond has increased the functional capacity for benthos, fish, birds, and wildlife. These physical changes along with the Phragmites control program also minimized the amount of Phragmites in the South Wetlands.

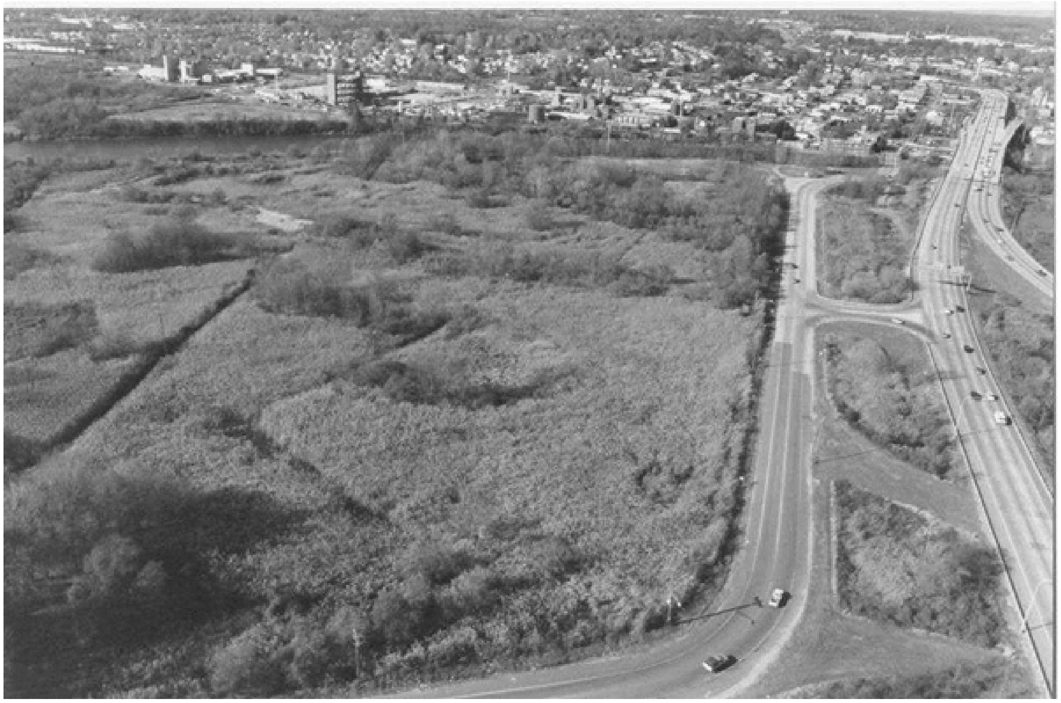


Figure 4. Pre-remediation (looking from the south).

Figure 5. Post-remediation (looking from the southeast).

A.50.5.3 Christina River

Final selected remedy: Dredge and monitoring

Cleanup activities for the Christina River included the dredging of 2.9 acres (one acre along the banks of the north landfill and the CibaSC plant, one acre upstream and one acre downstream of the facility). The Christina River study area consisted of 3.5 miles of river (1 mile upriver of the north drainage way, 0.5 mile along the site, and 2 miles down-river of the site). Sediments contaminated with heavy metals were removed (approximately 11,000 yd^3). On-site disposal of the sediments occurred in the south landfill, and restoration of the dredged areas was conducted. The restoration of dredged areas included backfilling all of the dredged areas and replanting the intertidal zones at the up- and downgradient areas. Sheet piling was used to prevent the migration of contaminated sediments during the wet dredging operations.

The pre-design delineation investigation was completed between March 1995 and February 1996. EPA approved the delineation in August 1996. Based on these data, three areas requiring remediation were identified. Subsequent confirmation sampling for the remedial areas was conducted and submitted to EPA in October 1996. Additional sediment sampling was completed in December 1997 to support the remedial design. Excavation began in 1998, and restoration was completed in 1999. The remedy for the Christina River was modified during the remedial design in several ways that greatly enhanced the cleanup. Once the contaminated areas of the river were delineated, it became apparent that there were areas of "marginal" contamination that were relatively small. DuPont proposed lowering the cleanup criteria and dredging these marginal areas thus eliminating the need for the extensive long-term monitoring program that was part of the ROD. As a result, EPA changed the site-specific sediment cleanup criteria for the Christina River. The changes were as follows:

Contaminant	Original Site-Specific Cleanup Criteria	Revised Site-Specific Cleanup Criteria	Effective Site-Specific Cleanup Criteria	Approximate Average Sediment Concentrations after Cleanup
Zinc	5,600 ppm	3,000 ppm	1,500 ppm	570 ppm
Lead	1,200 ppm	700 ppm	120 ppm	46 ppm
Cadmium	60 ppm	20 ppm	6 ppm	1.7 ppm

Why the remedy was selected: Prevent unacceptable impacts to environmental receptors.

Expected recovery time: NA

Project capital costs: $45,260,000 (includes soil and groundwater remedy costs)

Projected operation and monitoring costs: $48,155,000 (includes soil and groundwater remedy costs)

A.50.6 Monitoring Approach

For the north and south wetlands and the Christina River, the operations and maintenance included two inspections each year to monitor success of the plantings, evaluate the density and diversity of the plants, observe wildlife usage, look for erosion, and measure the percent coverage of invasive species.

A.50.6.1 North Wetlands

Remediation activities in the North Wetlands began in 1997 and restoration was completed in 1998. The EPA signed the Remedial Action Completion Report in June 1998. Maintenance and monitoring of the restoration began in June 1998 in accordance with the approved Maintenance and Monitoring Plan (DuPont CRG, 1998). The North Wetlands has passed its sixth year post restoration (1998 to 2003). Success metrics for vegetative cover, sediment stabilization, and invasive species were met within 3 years post-restoration. The site exceeds regional reference locations in terms of vegetative diversity and use by wildlife. Extensive data and information on the wetlands restoration progress has been collected from 1998 to the present as part of the annual and routine monthly inspections outlined in the Maintenance and Monitoring Plan (DuPont CRG, 1998) and Addendum (DuPont CRG 2002a).

Successful restoration of the North Wetland has vastly improved the functional capacity of this wetland to support fish communities in the Christina River. Fisheries surveys were conducted in 1999, 2001, and 2002 and have proven that the North Wetland supports a healthy, diverse fish community comprised of freshwater and estuarine species. The installation of a water control structure has successfully created a tidal open water habitat that maintains a continuous pool of water within the North Wetland and also allows for tidal flushing back into dense and diverse marsh vegetation. The increased (and increasing) complexity of this habitat type within the marsh provides niches for fish from all life stages (mature, mature spawning, juvenile, young-of-the-year, and larval fish). Currently, fisheries survey results suggest that one of the North Wetland's primary functions is a fish community nursery area. The collection of fishes from all life stages indicates that the aquatic habitat also functions as spawning and feeding grounds for numerous species. Overall, the abundance and structure of this fish community clearly demonstrate that the North Wetlands have been successfully restored to a level where the aquatic habitat now functions as an integral part of fisheries development and recruitment within the Christina River Watershed. (DuPont CRG, 2002a).

The well-established fish and benthic communities provide a substantial food source for birds that now frequent the area. Historically, the low quality habitat provided little niche space that resulted in low overall species richness. Use of the wetlands has increased over time and the bird community has become an integral part of the complex wetland food web. Both migratory and resident bird species that fill various trophic levels have been observed including piscivores (such as great egrets and osprey), invertivores (such as American robins and swallows), and granivores (such as red-winged blackbirds and sparrows). Many of these birds rely on the wetlands for foraging, nesting, breeding, and shelter.

A.50.6.2 South Landfill and Associated Wetlands

Remediation activities and restoration were completed in 1998 for the South Wetlands. The EPA signed the Remedial Action Completion Report in January 1999. Maintenance and monitoring of the restoration began in January 1999 in accordance with the approved Maintenance and Monitoring Plan (DuPont CRG, 1999). The South Wetlands has passed its fifth year post-restoration

(1999 to 2003). Success metrics for vegetative cover, sediment stabilization, and invasive species were met within the first three years post restoration. As with the North Wetlands, the South Wetlands exceeds regional reference locations in terms of vegetative diversity and use by wildlife. Extensive data and information on the wetlands restoration progress has been collected as part of the annual and routine inspections as outlined in the Maintenance and Monitoring Plan (DuPont CRG, 1999) and Addendum (DuPont CRG, 2002a).

Successful restoration of the South Wetland has vastly improved the functional capacity of this wetland to support fish communities in the Christina River. The drainage features continue to promote tidal flushing of the South Wetlands and water exchange within the South Pond. Fisheries surveys conducted annually in 2000, 2002, and 2003 have indicated that the South Wetland supports a healthy, diverse fish community comprised primarily of freshwater species with occasional use by estuarine species. The removal of dense stands of Phragmites, coupled with the restoration of drainage systems in the wetland have successfully created a tidally contiguous, open water habitat that regularly inundates the surrounding vegetation. The increased diversity of aquatic habitat types currently accessible to fish communities has provided niches for numerous species from all life stages (mature, mature spawning, juvenile, young-of-the-year, and larval fish). The presence of these various life stages indicates that the functional capacity of the South Wetland now includes spawning, feeding, and rearing grounds for fish communities. In addition, this wetland has continued to develop, attracting and supporting new species including obligate wetland fish such as the eastern mudminnow (Umbra pygmaea), collected in 2003. Overall, the abundance and structure of this fish community clearly demonstrates that the South Wetlands have been successfully restored to a level where the aquatic habitat now functions as an integral part of fisheries development, diversity, and recruitment within the Christina River Watershed.

The dramatic change in vegetative cover types has resulted in habitat opportunities for a variety of migratory and resident bird species. In addition, the well-established fish and benthic communities provide a substantial food source for birds that now frequent the area. Where the original monotypic stand of Phragmites provided poor bird habitat, the current habitat provides space for all trophic levels of birds. Many of these birds rely on the wetlands for foraging, nesting, breeding, and shelter.

A.50.6.3 Christina River

Maintenance and monitoring began in September 1999 in accordance with the approved Maintenance and Monitoring Plan. The EPA signed the Remedial Action Completion Report in February 2000. All success metrics established for the Christina River Area were met within the first few years of monitoring. All areas remained stable with increases in vegetative cover and species richness. Natural recruitment of plants resulted in the successful establishment of a diverse emergent plant community. In 2003, DNREC activities on the Christina River resulted in the disruption of the down-river area. A 10-foot wide mosquito control ditch was cut through the restoration site. Because this action was undertaken by the state, no corrective actions by DuPont was required. However, EPA is requiring DNREC to sample in the dredged area to ensure that there is no contamination in the upper several feet of sediment.

In order for the remedy at the river to be protective in the long-term, a determination must be made as to whether sediment contamination found in deeper sediment at an adjacent site (Koppers, DE, Superfund Site – also a case study in this document) and a nearby potential wetlands mitigation site is from DuPont-Newport Superfund Site and, if so, if it poses a risk to human health and the environment.

A.50.7 Site References

USEPA. 1993. Record of Decision (ROD) for the DuPont-Newport Superfund Site. USEPA. August 26, 1993.

USEPA. 2010 Third Five-Year Review Report, E.I. DuPont, Newport Superfund Site; Newport, Delaware. Mach 31, 2010.

DuPont CRG, 1998, DuPont CRG. 1998. Monitoring and Maintenance Plan – North Wetlands, Newport Superfund Site, Newport, Delaware.

DuPont CRG, 1999, DuPont CRG. 1999. Monitoring and Maintenance Plan – South Wetlands, Newport Superfund Site, Newport, Delaware.

DuPont CRG 2002a, DuPont Corporate Remediation Group (CRG). 2002a. 2002 Annual Inspection Report – North Wetlands, Newport Superfund Site, Newport, Delaware.

A.51 Naval Station - McAllister Point Landfill, RI

A.51.1 Summary

Environment:	Landfill/marine
Scale:	
Contaminants of Concern:	PCBs, PAHs, copper, nickel, anthracene, fluorine, and pyrene Near shore area contains: ash, glass, pottery, brick, metal pieces, and larger debris (metal, concrete, and submarine netting).
Final Remedy:	Approximately 895,540 gallons of water from water collection pond treated and discharged to Newport publicly-owned treatment works. Approximately 20% of dredged material (rocks more than 6 inches in diameter) decontaminated and reused. Small fraction of dredged material (≈500 tons) decontaminated and sent off site for recycling or disposal. Remaining dredged material dewatered and disposed at McAllister Point Landfill or another off-site location.

A.51.2 Site Description

Year: 1996

Water Depth: 3 ft at mean low water line

Target Volume: 34,000 yd^3

Actual Volume Removed: 2,700 m^2

A.51.3 Remedial Objectives

Copper: 52.9 (ppb in pore water)

Nickel: 33.7 (ppb in pore water)

Anthracene: 513 (ppb in sediment)

Fluorine: 203 (ppb in sediment)

Pyrene: 2,992 (ppb in sediment)

Total PCBs: 3,634

Landfill materials estimated up to 15 ft thick at revetment in central portion of the landfill and taper to less than 1 ft at north and south ends.

Contaminated area: ≈ 47 acres adjacent to the landfill

A.51.4 Remedial Approach

Mechanical clamshell. Installation of multi-media, low-permeability cap over landfill. Passive gas vent system installed during construction of cap to dissipate potential for gas buildup that could disturb the capping materials.

A.51.5 Monitoring

Turbidity curtains were installed at the perimeter of the near shore and elevated risk offshore areas to minimize the migration of sediments during the dredging activities. Turbidity curtains were also used as the dredging progressed to separate confirmed clean areas from active dredging areas.

After an area was confirmed clean, area was backfilled with materials appropriate to the area and graded. The surface of the cap is vegetated and graded to promote runoff of precipitation, thus minimizing potential infiltration that could cause further leaching. Non-contaminated areas were capped with a RCRA Subtitle C multi-layer cap.

RAOs/project objectives achieved? Targeted cleanup goals were met at all locations.

A.51.6 References

USEPA Superfund Record of Decision: Newport Naval Education & Training Center EPA ID: RI6170085470. Sep 1993. http://www.epa.gov/superfund/sites/rods/fulltext/r0193081.pdf.

USEPA. Final Five-Year Review Report for Naval Station Newport. Dec 1999. http://www.epa.gov/region1/superfund/sites/netc/34986.pdf.

USEPA. Five-Year Review for Naval Station Newport. Dec 2004. http://www.epa.gov-/region1/superfund/sites/netc/213065.pdf.

A.52 Ottawa River, Toledo, OH

A.52.1 Contacts

Great Lakes National Program Office

A.52.2 Summary

Environment:	Freshwater River and Creek
Scale:	Full
Contaminants of Concern:	PCBs and PAHs
Source Control Achieved Prior to Remedy Selection?	Partial source control has been achieved. Five industrial sites have been cleaned up; three landfills have been capped, and the City of Toledo is working to control combined sewer overflows.
Final Remedy:	Hydraulic dredging and off-site disposal

A.52.3 Site Description

Primary source(s): Historical pollution from landfills, industrial facilities, and CSOs.

Location: The project is part of the Ottawa River/Maumee River Area of Concern (AOC) located in Toledo, Ohio. The sediment cleanup focuses on approximately 6 miles of the Ottawa River and the approximately 1 mile of Sibley Creek, a tributary to the Ottawa River.

Site history: Historical industrial activities, CSOs, and releases from landfills has resulted in sediment contamination within the Ottawa River and Sibley Creek. Contamination in the sediment of the Ottawa River is a leading cause of state advisories against eating certain fish from the river and Maumee Bay. The cleanup will reduce the mass of PCBs entering Lake Erie. A consortium of parties have come forward to provide matching dollars for remediation of contaminated sediments. These parties include the City of Toledo; Allied Waste North America, Inc.; E.I. du Pont de Nemours and Co.; Honeywell, Inc.; Illinois Tool Works, Inc.; Unite Technologies Corp.; Varta Microbattery, Inc.; the Mosaic Co.; Perstorp Polyols, Inc.; and Grand Trunk Western Railroad.

A.52.4 Remedial Objectives

Beneficial use impacts include restrictions on fish and wildlife consumption, excessive algae growth, and degraded fish and wildlife habitat.

A.52.5 Remedial Approach

Dredging was followed by off-site disposal in a landfill. Dredged sediment contaminated with high levels of PCBs will be sent to a facility designed and permitted to accept this type of waste.

Remaining sediment will likely go to Toledo's Hoffman Road landfill.

Approximately 250,000 yd^3 of sediment contaminated with PCBs and PAHs were hydraulically dredged and dewatered using Geotubes. The majority of the contaminated sediments were disposed of in the Hoffman Road Landfill.

Why the remedy was selected: Elevated levels of PCBs and PAHs has resulted in degraded habitat and restrictions on the consumption of fish and wildlife. Dredging was selected because a suitable disposal site was available.

A.52.6 Costs

The $49 million Ottawa River project was funded by the GLLA and the Ottawa River Group on a 50/50 basis.

A.52.7 Advantages and Limitations

The project successfully leveraged GLLA funding to complete a sediment cleanup.

A.52.8 References

Ottawa River Lagacy Act Cleanup; add period to end of reference. http://www.epa.gov-/glla/ottawa/.

A.53 Ottawa River, Canada

A.53.1 Summary

Environment:	Freshwater
Scale:	
Contaminants of Concern:	PCBs: Some samples were as high as 74,000 ppm and fish concentrations as high as 500 ppm. About 1/2 of the 104 sediment samples from the 28 cores contained PCBs at <50ppm. Less than 10% of the samples contained PCBs >10,000 ppm
Final Remedy:	Excavated material was transported to a staging pad for gravity dewatering then fed into a pug mill via track hoe. 14,975 tons of dewatered, stabilized material were disposed as TSCA waste at Wayne Disposal facility in Bellvue, MI. 881 Tons of soil were disposed as nonhazardous waste at Evergreen RFD in Norwood, OH. The material was mixed with 8–10% of pozzament 100, a stabilizing agent, to reduce free liquid, cured, then sent to a landfill.

A.53.2 Site Description

Year: 1998

Contaminated sediment area is a tributary that is 975 ft long and 90 ft wide at its mouth, and tapering to a 10 ft width at the origin.

Tributary Sediment (soft, silty) and adjacent wetland soils

Water Depth: 0–40 ft

Target Volume:

6,500 yd^3 of sediment (from the tributary)

Actual Volume Removed:

8,039 yd^3 (in situ) sediment

1,653 yd^3 of wetlands soil

A.53.3 Remedial Objectives

PCB <50ppm

Sediment thickness: 5–15ft. 1ft of sediment was proposed to prepare the area for use in staging sediment removal equipment activities.

Dredged depths: 5–15 ft

Conventional earth moving equipment was used.

A.53.4 Remedial Approach

Existing storm sewer pipes that drain into the tributary were re-routed into a newly constructed 660 ft long stormwater channel.

A.53.5 Monitoring

Resuspension:

To hydraulically isolate the tributary from the Ottawa River, 164 linear feet of steel sheeting was installed at the mouth of the tributary. Water was pumped out and treated on site. This eliminated the tributary from acting as any sort of surface water flow channel.

Residuals:

Dredging event Area 1 current Level: <0.1 ppm PCB

Dredging event Area 2 current Level: 4.6 ppm PCB

Dredging event Area 3 current Level: 0.6 ppm PCB

Dredging event Area 4 current level: 0.5-38 ppm PCB

The tributary was backfilled with clean fill to a final design grade, covering any residual materials with at least 5 ft of backfill.

A.53.6 References

U.S. EPA. Great Lakes Act Project to Remove Polluted Sediment. Jan 2010. http://www.epa.gov-/glla/ottawa/ottawastart.pdf.

U.S. EPA. Great Lakes Legacy Act Ottawa River Cleanup Has Begun. No. 10-OPA056. May 2010. http://y-osemite.epa.gov-/opa/admpress.nsf/0/9cb5fd7102773a51852577290052cc1b?OpenDocument.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.54 Pegan Cove, MA

A.54.1 Summary

Environment:	Freshwater
Scale:	Full
Contaminants of Concern:	PCB: 0.15 to 4.1 ppm (average of 1.7 ppm)
Final Remedy:	Hydraulic cutterhead dredge pumped sediment directly into geotextile bag. Sediment removed by hydraulic dredge conveyed through slurry pipeline to dewatering stations set up within open areas along eastern shoreline of NSSC facility. After dewatering, geotextile bags were cut open and sediment was trucked to licensed off-site disposal or treatment facility.

A.54.2 Site Description

The Natick Labs/U.S. Army Natick Soldier systems center (NSSC) site (OU 2) is located at Pegan Cove in Natick, MA. PCBs were fairly widespread throughout the cove at levels above the estimated risk threshold of 1 mg/kg (area exceeding this threshold is shaded in green in Figure 6-1 (a)). Elevated PCB levels were detected in fish. Except near a stormwater outfall, where elevated PCBs in sediment were 15 inches deep, PCBs were present primarily in surface sediment at 0–6 inches deep. A focused sampling in 2007 along four transects (visible in figure) spanned the entire cove. The risk threshold was based on a human exposure through fish consumption. Water depth in the cove ranged from 0 to 10 ft. The sediments were primarily silty clay, activities took place in 2010, the contaminated sediment area was 34 acres, and the target volume was 2,510 yd^3.

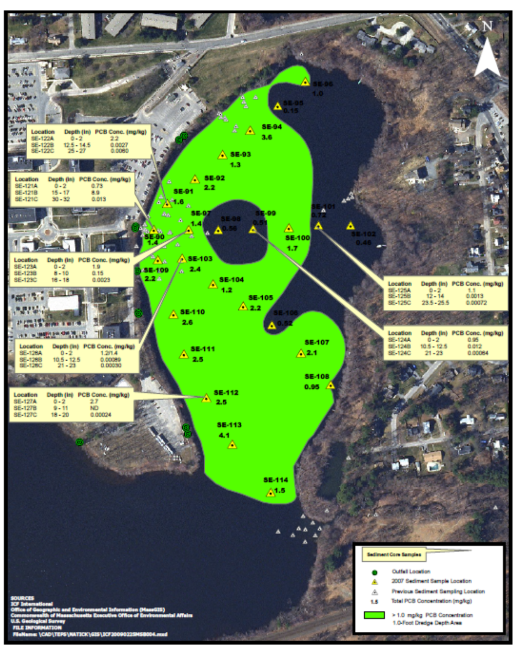
A.54.3 Remedial Objectives

Remedial objectives included reducing PCB SWAC in Pegan Cove below 1 ppm. There were four hotspots: three 6-inch dredge depth areas and one 12-inch dredge depth area in front of the main stormwater outfall.

A.54.4 Remedial Approach

MNR was considered feasible because there was no source of fresh sediment available for natural deposition in the cove. Removal by hydraulic dredging was selected. A 56-foot long barge (with a draft of 2.5 ft and a maximum dredge depth of 15 ft) was used to dredge approximately 3,000 yd³ of sediment. A swing ladder supported the cutterhead of the dredge. Final dredge cut depths within hot spot Areas 1 and 3 were designed to be 6 inches and Area 2 dredge cut depths were designed to be 12 inches with no less than 10 inches removed. Ensuring target area coverage within each hot spot was done by overlapping dredging sweeps. After dredging, the dredged area was backfilled with a thin layer of sand, without which the SWAC goal could not be efficiently achieved. The dredged material was dewatered in Geotubes, dried, tested, and shipped to a waste disposal facility.

The three hot spots shown in Figure 6-1b represented areas that would have to be dredged to reach a SWAC of 1 ppm across the entire cove. The ROD for the site stated that although some sediment containing PCBs would remain on site, the average PCB concentration within Pegan Cove after hot spot dredging would be less than the sediment cleanup goal of 1 mg/kg. Because the sediment removed from hot spot areas would be disposed of off site, O&M activities and five-year reviews of the sediment remedy would not be required. The hydraulic dredging operation was completed in 2010 and the site subsequently received no further action (NFA) status.



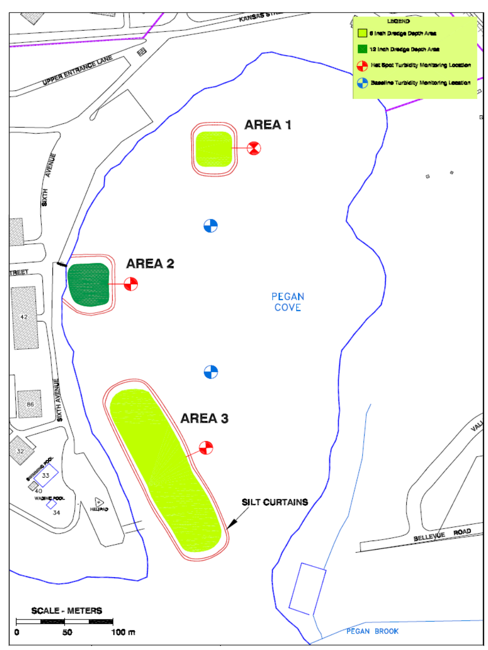


Figure 1. The Pegan Cove site with (a) the green area showing the area where PCBs exceeded 1 ppm and (b) the three hot- spots that were removed by hydraulic dredging to complete the remediation. A fish advisory that is already in effect will continue.

A.54.5 Monitoring

Silt curtains placed separately around each of four hotspots. Two silt curtains installed around perimeter of each sediment hot spot. First (or interior) silt curtain acts as primary containment, while second (or exterior) silt curtain installed right behind first acts as secondary containment. Water monitoring done consistently outside silt curtains and sample readings never exceeded action threshold. Double silt curtains worked well at this site.

Average PCB concentration after dredging were less than 1 ppm. Four dredged areas were backfilled with clean sand, which lowered postdredging concentration from 1.03 to 0.97 ppm PCBs.

There is no long-term monitoring associated with this alternative because "No Further Action" status was granted after the cleanup met the proposed SWAC goal.

RAOs/project objectives achieved? The RAOs for this site were met.

A.54.6 References

PCB Contaminated Sediment Remediation in Waukegan Harbor. http://www.ijc.org/php/publications/html/cases/waukegan/waukegan.html.

Kevin J. Palaia, S. Reichenbacher, J. Connolly. Superfund Sediment PCB Cleanup Using Green & Sustainable Remediation Practices at the U.S. Army Natick Soldier Systems Center. http://www.epa.gov/region1/superfund/sites/naticklab/536503.pdf (ICF,2011).

USEPA Superfund Record of Decision: Natick Laboratory Army Research, Development, and Engineering Center EPA ID: MA1210020631. Sep 2001. http://www.epa.gov/superfund/sites/rods/fulltext/r0101547.pdf .

ICF International. First Five-Year Review Report for U.S. Army Soldier Systems Center (SSC) Town of Natick. SDMS 266254. Jan 2007. http://www.epa.gov/region1/superfund/sites/naticklab/266254.pdf.

Final Second Five-Year Review Report (2007-2011) for the Natick Soldier Systems Center. SDMS DocID 508767. March 2012. http://www.epa.gov/region1/superfund/sites/naticklab/508767.pdf.

A.55 Penobscot River (Dunnett's Cove), Maine

A.55.1 Contacts

Regulatory Contacts:

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Maine Department of Environmental Protection
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A.55.2 Summary

Environment	River
Scale	Full
Primary source (s):	Sewer discharge from a manufactured gas plant.
COCs	Coal tar NAPL
Final Remedy	Cap designed to trap NAPL and dredging

A.55.3 Site Description

From 1851 to 1963, Bangor Gas Works operated a manufactured gas plant. Wastewater from the plant, containing coal and oil tar, was discharged into a sewer that in turn discharged to the Penobscot River.

CSM summary: Much of the tarry sediment hardened at the bottom of the river but a portion of the tar impacted sediment remains unhardened in what has been termed the active zone. Tar is present in sediments over approximately 11 acres of Dunnett's Cove. Gas released from the contaminated sediment facilitates NAPL migration to the surface.

Based on observation, 3 conditions were necessary to facilitate NAPL migration:

- The sediment contains liquid tar
- The sediment produces gas bubbles at a rate to increase the buoyancy of tar and facilitate upward migration
- The gas is in contact with the tarry sediment.

A.55.4 Remedial Approach

Final selected remedy: Cap designed to trap NAPL

Bench scale tests showed that a sand cap allowed gas to migrate upward carrying NAPL. A second bench scale test showed that sand amended with organophilic clay also exhibited NAPL breakthrough. The selected remedy, a low permeability AquaBlok cap with underlying gas venting layer, addresses the problem with gas accumulation and NAPL migration.

Lessons learned: Facilitated transport of NAPL at manufactured gas plant (MGP) sites must be taken into consideration. A sand cap by itself or with an amendment may not effectively isolate NAPL contamination at MGP sites.

Additionally, source area characterization is important. Sediment in the designated active zone posed the greatest exposure risk.

Why the remedy was selected: The cap only needed to be replaced in those areas that still posed an unacceptable exposure risk.

A.55.5 References

Case Study, Sediment Remediation, Bangor Landing, Bangor, ME, Maine Department of Environmental Protection, April 2010, http://www.newmoa.org/cleanup/cwm/sediments10/HowattMECaseStudy1.pdf.

A.56 Pettit Creek Flume, NY

A.56.1 Summary

Environment:	Freshwater
Scale:	Full
Contaminants of Concern:	DNAPL and VOC, Semi-Volatile
Final Remedy:	Dredged grids, 1,840 yd^3 was processed and put in super sacks. 160 yd^3 was treated and disposed in a commercial landfill.

A.56.2 Site Description

River sediment

Year: 1994

Target Volume: 2,000 yd^3

Contaminated sediment area: one-acre cove in Durez Inlet of Little Niagara River

Actual Volume Removed: 1134 tons

A.56.3 Remedial Objectives

Remove all visual evidence of DNAPL in the dredge work area.

A.56.4 Remedial Approach

Diver assisted suction hydraulic dredging. Dredge work area divided into 540, 10×10 grids to facilitate control of dredging operations.

A.56.5 Monitoring

Resuspension:

Sheet pile control wall and silt curtain installed prior to dredging. Silt control wall ran parallel to cove cofferdam near east bank of river. Sediment removed between silt control wall and cofferdam.

Residuals:

Five sediment samples were taken after dredging and concentrations were significantly lower than before dredging.

A.56.6 References

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.57 Pine Street Canal, VT

A.57.1 Contacts

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A.57.2 Summary

Environment:	Canal
Scale:	Full
Contaminants of Concern:	PAHs, VOCs, metals, coal tar NAPL
Final Remedy:	Sand cap and cap with organophilic clay amendment

A.57.3 Site Description

Primary source(s): Plant wastewaters and residual oil and wood chips saturated with organic compounds were directly discharged or disposed of in the Pine Street Canal wetland.

From 1908 to 1966 a coal gasification plant began operating on Pine Street, southeast of the canal. In the 1960s and 70s, an oily material was detected seeping from the wetland into the canal.

A.57.4 Remedial Approach

Final selected remedy: Sand cap and cap with organophilic clay amendment

In 2002-2003, a nominal 3' sand cap was initially placed over the coal tar contaminated sediments and sludges and over sunken barges that were deemed to be of archeological significance. During placement over the thickest layer of contaminated sludge (approximately 10-12 ft thickness of oily sludge), sediment waves formed and some of the sludge and NAPL was displaced through cribbing walls around the canal. Continued consolidation and gas ebullition also led to NAPL release through the cap in this area.

In 2009, the sand cap was replaced with an amended cap in the high seepage area. The amended cap was composed of multiple layers of reactive core mat containing organophilic clays to absorb any NAPL that might be mobilized. The potential displacement of coal tar through the porous cribbing bounding the canal is being addressed by a 200-300 ft long vertical barrier and passive recovery wells installed during the 2012 field season. The sand cap throughout the rest of the canal was left in place and appears to be effective at containing the contaminants.

This site illustrated that mobile NAPL can penetrate a sand cap, particularly if hydraulic forces or gas migration encourage such penetration.

Why the remedy was selected: The organophilic clay mat was used to replace the original sand cap in areas where NAPL mobilization was occurring due to gas ebullition.

A.57.5 References

Pine Street Canal, Waste Site Cleanup and Reuse in New England, USEPA Region 1. http://yosemite.epa.gov/r1/npl_pad.nsf/31c4fec03a0762d285256bb80076489c/f8cfe11e53efa23c8525691f0063f6e8!OpenDocument.

A.58 Pioneer Lake, OH

A.58.1 Summary

Environment:	Freshwater
Scale:	Full
Contaminants of Concern:	VOC PAH (as high as 742 ppm) BTEX ranges from 123–1,873 ppm Coal tar
Final Remedy:	Hydraulic cutterhead dredge. Water treatment consisted of pumping dredged water from settling basin through carbon filter units. Phase 1: 556 tons of nonhazardous coarse sediments–Williams County Landfill 189,450 gallons of nonhazardous pumpable sludge–City Environmental Phase 2: 916 tons of coarse sediment–WCL 226,911 gallons of nonhazardous pumpable sludge–Evergreen RDF 4,360 tons of solidified sludge (including 1,193 tons of kiln dust) –Evergreen Treatment process continued until limits were met and water could be released into lake.

A.58.2 Site Description

Lake sediment, sand, gravel pit

Year: 1997

Target Volume: 6,600 yd^3

Actual Volume Removed: 6,600 yd^3

A.58.3 Remedial Objectives

< $1x10^{-4}$ excess lifetime cancer risk value in lake sediment resulting in target levels:

Ethylbenzene: 480 ppm

Toluene: 970 ppm

Total xylene: 9700 ppm

Naphthalene: 360 ppm

Fluorine: 360 ppm

Anthracene: 2700 ppm

Fluoranthene: 360 ppm

Pyrene: 270 ppm

Contaminated sediment thickness: 0.5-3 ft

Contaminated sediment area: 1 acre located in the southern portion of the Pioneer Lake

Also, a 60x50x8 ft asphalt pit located on shore.

A.58.4 Remedial Approach

Hydraulic cutter head dredge

A.58.5 Monitoring

Resuspension:

Silt curtains were used to control suspension. 18 inch skirted floating absorbent boom used to contain contaminants.

Performance:

There were two phases for this project.

All contaminants were co-located so dredging accounted for them all.

Residuals:

No capping was needed for this site since goals were reached after dredging was completed.

A.58.6 References

Stafford, Carolyn. EPA to clean up Lake Pioneer. The Bryan Times, Sep 22, 1995, Vol 47, No. 224. Bryan, OH. http://news-.google.-com/newspapers?nid=799&dat=19950922&id=QKFTAAAAIBAJ&sjid=oIcDAAAAIBAJ&pg=6034,49

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.59 Port of Portland, OR

EPA designated Portland Harbor a Superfund site because sediments in a stretch of the Lower Willamette River contain metals, pesticides, PCBs, petroleum products, and other contaminants at levels that threaten human health and the environment. Marine Terminal 4 is located within the Portland Harbor Superfund Site. Historically, the terminal was used for loading and unloading petroleum products, pencil pitch, liquid fertilizer, soda-ash, metals, and agricultural products.

The Port of Portland has worked closely with the Environmental Protection Agency to develop a plan to clean up contaminated sediment at marine Terminal 4 in North Portland. The first phase of that cleanup plan was successfully completed in fall 2008.

During the phase 1 work, the Port dredged 12,819 yd^3 of sediment contaminated with petroleum, metals, and polycyclic aromatic hydrocarbons. With a fish diversion mesh and turbidity curtain in place, and with continuous modifications to the dredging process to reflect river bottom conditions, dredging activities met all water quality goals and were completed on time and within budget. Dredged sediment was transported by barge for disposal at a landfill near The Dalles.

Additionally, contaminated sediment in the back of Slip 3 was isolated with a cap made of an 18-inch layer of an organoclay-sand mix. The mix was placed by releasing from a clamshell bucket just above the surface. The organoclay-sand cap was covered with sand and stone armor. Dredging was not practical in this area because of concern for slope stability of a timber bulkhead.

A.59.1 Advantages and Limitations

Certain structures can make dredging nearby impractical. In this case, a timber bulkhead may have structurally failed if adjacent sediment was removed. In such areas, capping can be a viable alternative.

A.59.2 References

Port of Portland and period at end of reference. http://www.portofportland.com/t4_ea_home.aspx.

A.60 Port of Tacoma Piers 24 and 25, WA

A.60.1 Summary

Environment:	Tidal flat
Scale:	Full
Contaminants of Concern:	Metals (zinc, copper, mercury), phenanthrene, dibenz(a,h)anthracene, PCBs, and hexchlorobutadine (HCBD)
Final Remedy:	Debris removal, excavation, and capping

A.60.2 Site Description

The Port of Tacoma's Piers 24 and 25 are located in Tacoma, Washington at the mouth of the Hylebos Waterway, which is part of the Commencement Bay/Tideflats Superfund Site. Chemicals were primarily introduced to the site by direct and indirect discharges of contaminated wastewater from the now-demolished Tacoma/Asarco Smelter. Cleanup activities began in the Hylebos Waterway in 2002 and a 2005 Consent Decree required capping under Piers 24 and 25.

A.60.3 Remedial Approach

Final selected remedy: Debris removal, excavation, and capping

The Piers 24 & 25 Embankment Capping Area includes intertidal and subtidal areas along an embankment approximately 1,200 ft long and including the wharf covered slopes beneath Piers 24 and 25. Capping began in October 2007 and was finished in 2009.

During the construction of the caps and the armor stone on the wharf covered slopes beneath Piers 24 and 25, a few practical methods of reducing construction impact on water quality were effectively implemented. Debris removal, PCB hot spot excavation, and metallic debris pile excavations were conducted during low tide periods as much as practical. Shotcrete capping materials were placed when possible during low tide and using quick-set formulation. Other capping materials were also placed in the dry as possible and placed using low-disturbance techniques below the waterline when necessary. The quantity of capping materials used to construct a "toe berm" at the base of the slope was significantly higher than anticipated due to small design tolerances, difficulty of placement in relatively soft sediments, and difficulty with controlling settlement and downslope movement.

A.60.4 Monitoring

Pre- and post-construction samples showed no exceedances of Commencement Bay sediment quality objectives (SQOs) and visual inspections confirmed that the caps remain intact.

This project had issues with community acceptance. A technically feasible option was proposed previously but was rejected by a community who felt their input was not sought/incorporated thoroughly enough. They then re-worked their entire plan and added significant stakeholder and community input/review to come up with a new accepted feasible option. This held up remediation by several years.

A.61 Queensbury NMPC

A.61.1 Summary

Environment:	Shoreline
Scale:	Full
Contaminants of Concern:	PCB contamination was found in Hudson River sediment in an area extending 180 ft offshore and 800 ft downstream from the site boundary.
Final Remedy:	Excavated sediments were allowed to drain for a week on constructed dewatering pads. Contaminated sediment was transported to a commercial off-site landfill (Model City, NY).

A.61.2 Site Description

Year: 1996

Target Volume: 5,000 yd^3

Actual Volume Removed: 6,800 yd^3

A.61.3 Remedial Objectives

Remedial objectives were 1ppm for surface sediments and 10ppm for subsurface sediments, below 1 ft of depth.

Contaminated sediment area: 0.3 acre shoreline area

A.61.4 Remedial Approach

Water level was lowered 4 ft to expose the targeted river bank and near shore sediments. This was done by using controls at the nearby Sherman Island Dam.

A.61.5 Monitoring

A reinforced silt fence was installed at water line to prevent water movement. Jersey barriers wrapped with geotextile were installed at the upper inland boundary, and removal was accomplished in between.

PCB concentrations in several fish species declined following remediation.

The excavated area was backfilled with topsoil and rip-rap. The upland portion was seeded and planted with shrubs and trees.

A.61.6 References

Field, L.J., J.W. Kern, and R.J. Sloan. PCB Concentrations in Fish Following Remediation of a Small Hazardous Waste Site. http://www.darrp.noaa.gov/library/pdf/1452_SETAC_07_Fish_PCB_poster.pdf.

USEPA. Five-Year Review Report for the Niagara Mohawk Power Corporation Superfund Site. Aug 2006. http://www.epa.gov/superfund/sites/fiveyear/f2006020001043.pdf.

USEPA. Five-Year Report for the Niagara Mohawk Power Corporation Superfund Site. SDMS DocID 111359. Aug 2011. http://www.epa.gov-/superfund/sites/fiveyear/f2011020004031.pdf.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.62 Reynolds, NY

A.62.1 Summary

Environment:	Freshwater
Scale:	Full
Contaminants of Concern:	PCB Max: 1,300 ppm, PAH max: 3734 ppm, total dibenzofurans (TDBFs) Max: 0.44 ppm All collected within 500 ft of the Reynolds outfalls
Final Remedy:	Mechanically dredged 69,000 yd^3 of sediment with PCB concentrations less than 50 ppm were stabilized with Portland cement and disposed of in the landfill on the facility. The remaining 16,655 yd^3 (14,920 tons of sediment with PCB concentrations greater than 50 ppm and 5,360 tons of sediment with PCB concentrations greater than 500 ppm) were shipped to Chemical Waste Management in Model City, New York, an approved hazardous waste facility, for disposal.

A.62.2 Site Description

Year: 2004

Near shore area

Actual Volume Removed: 85,655 yd^3

A.62.3 Remedial Objectives

PCB: 1 ppm

Total PAH: 10 ppm

TDBF: 1 ppb

21.8 acres were dredged out of the 30 that was estimated.

A.62.4 Remedial Approach

Dredging was performed using three cable arm environmental buckets (two 5 ½ yd^3 and one 2 1/2 yd^3). Equipment for each dredging operation included a derrick barge with a fixed boom mounted crane for bucket operation and the GPS positioning system WINOPS.

A.62.5 Monitoring

Resuspension:

Containment system of 3,829 ft of steel interlocking sheet pile panels installed to completely enclose dredge area, reducing potential for sediment migration. Combination of herbicide Aquathol and aquatic non-crop herbicide Reward applied within the sheet piled area for vegetation suppression.

Area C used silt curtains as containment barrier.

Performance:

Multiple dredging passes required for some areas.

Residuals:

Sample results show 12 cells did not meet cleanup goal of 1 ppm PCBs even though cells underwent several dredge passes. As a result, 0.75-acre area was backfilled with three-layer system to achieve cleanup goal. Remaining exposed sediments average 0.8 ppm PCBs within remaining 255 cells— below cleanup goal.

23 cells containing total PAHs between 10 and 20 ppm not capped—determined that low molecular weight PAHs would readily break down over short period of time bringing total PAH level for cells below 10 ppm.

A.62.6 References

USEPA Superfund Record of Decision: Reynolds Metals Co EPA ID: NYD002245967. Sep 1993. http://www.epa.gov/superfund/sites/rods/fulltext/r0293201.pdf.

USEPA. Five-Year Review Report Reynolds Metals Company Site. Apr 2006. http://www.epa.gov/superfund/sites/fiveyear/f06-02018.pdf.

USEPA. Five-Year Review Report Reynolds Metals Company Site. Feb 2011. http://www.epa.gov/superfund/sites/fiveyear/f2011020003794.pdf.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.63 Randall Reef, ON

Randle Reef Sediment Remediation Project - Hamilton Harbour Ontario, Canada)

A.63.1 Site Description

Embayment located at the western tip of Lake Ontario and connected to the lake by a ship canal across the sandbar that forms the bay.

Contaminants of concern: Heavily contaminated coal tar (polycyclic aromatic hydrocarbons) as well as metals

A.63.2 Remedial Objectives

Remove the major source of highly contaminated PAHs (and metals) from Hamilton Harbour

Summary of Project Plan:

- Construct a 7.5 hectare Engineered Containment Facility (ECF) with environmental features.
- Minimize disturbing the most highly contaminated sediment (130,000 m3 in situ) by building the ECF on top of this material.
- Remove 500,000 m^3 by dredging and place within ECF.
- Treat sediment by dewatering.
- Isolate/cap sediments in U.S. Steel Intake/Outfall Channel.
- Create a multi-use facility with port features and open green space.

A.63.3 Remedial Approach

A detailed feasibility study that compared remediation alternatives was completed with public input incorporated. Removal combined with containment approach for sediment remediation was selected for Randle Reef. Of the limited number and type of alternatives available for large-scale sediment remediation, hybrid approaches that include containment generally offer the best combination of environmental protection, practicality, and cost-effectiveness.

A.63.4 Costs

$105M over 10 years (technical)

A.63.5 Advantages and Limitations

Community: This project had issues with community acceptance, a viable option was proposed previously but was rejected by a community who felt their input was not sought/incorporated thoroughly enough. They then re-worked their entire plan and added significant stakeholder and community input/review to come up with an acceptable feasible option. This held up remediation by several years.

A.63.6 Resources

Hamilton Harbour Remedial Action Plan. http://ec.gc.ca/default.asp?lang=En&n=976258C6-1&news=491B73F8-2719-4B56-B632-5C1327F9350F.

A.64 Sheboygan River and Harbor, WI

A.64.1 Contacts

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State of Wisconsin Technical Representative:
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A.64.2 Summary

Environment:	Sheboygan River Western Shore of Lake Michigan
Scale:	Full
Contaminants of Concern:	Polychlorinated biphenyls (PCBs)
Source Control Achieved Prior to Remedy Selection?	Yes – upland soils and groundwater controls
Final Remedy:	Removal and MNR: Upper River removal of between 20,774 yd^3 of PCB-contaminated sediment to achieve a removal of 88% of the PCB mass in the soft sediments. This would achieve a Surfaced Weighted Area Concentration (SWAC) of 0.5 parts per million (ppm) in the combined Upper and Middle River segments. Middle River no action required. Lower River removal of 16,158 yd^3 of PCB-contaminated sediment to achieve soft sediment SWAC of 0.5 parts per million (ppm). Inner Harbor removal of 34,390 yd^3 of PCB-contaminated sediment to achieve soft sediment SWAC of 0.5 ppm.
Expected Recovery Time:	19 years
MNR viewed as a success?	MNR is considered an element of the cleanup process

A.64.3 Site Description

Sheboygan River and Harbor, Sheboygan County, Wisconsin. CERCLIS ID: WID 980 996 367

Sheboygan River and Harbor includes the lower 14 miles of the river from the Sheboygan Fall Dam downstream and including the Inner Harbor. The site includes the Upper River, Middle River, Lower River, and Inner Harbor. This segment of the river flows through the communities of Sheboygan Falls, Kohler, and Sheboygan before entering Lake Michigan. Tecumseh was located adjacent to the Sheboygan River in Sheboygan Falls, Wisconsin. The primary sources of contamination at this site were discharges from Tecumseh Products Co., a manufacturer of refrigeration and air conditioning compressors and gasoline engines.

The United States Army Corps of Engineers (USACE) constructed the Sheboygan Harbor and navigation channels in the early 1920s and performed routine maintenance dredging activities until 1979 when sediment samples indicated moderate-to-high levels of lead, zinc, PCBs, chromium, and moderate levels of arsenic were present. PCBs were found in sewer lines that discharged from Tecumseh's facility to the river. PCBs were also found in hydraulic fluids used in the Tecumseh Products Company's Diecast Division manufacturing processes. Contamination was high in sediments immediately surrounding the Tecumseh plant but decreased downstream. Tecumseh performed preliminary cleanup actions in the late 1970's following the USEPA's issuance of PCB regulations.

In 1989 and 1990, EPA requested Tecumseh to conduction actions to remove about 5,000 yd^3 of contaminated sediment which was stored in two containment facilities at Tecumseh's Sheboygan Falls plant. In addition, approximately 1,200 square yards of highly contaminated sediment were capped or "armored" in place to prevent contaminants in the sediments from entering the river.

CSM summary: The Conceptual Site Model includes contaminated sediments in the Upper River, low levels of contaminated sediments in the Middle River, contaminated sediments in the Lower River and Inner Harbor, contaminated soils in the River Floodplain, and contaminated groundwater at Tecumseh's Sheboygan Falls Plant.

A.64.4 Remedial Objectives

USEPA developed a sediment cleanup goal to protect human health, based on the consumption of bass under the reasonable maximum exposure scenario (RME). The goal would range from 0.005 ppm which equals a 1 in a million risk to 0.5 ppm which would equal a 1 in ten thousand risk. The 10^{-6}, or 1 in a million, risk level is the departure point for managing site risks.

Based on the NOAA Aquatic Risk Assessment, PCB-contaminated sediment pose a risk to fish and wildlife, U.S. EPA analyzed the ecological risk, in consultation with the natural resource trustees. A sediment cleanup goal between 0.05 ppm and 1.0 was determined to protect fish and wildlife. The 0.05 ppm level represents the No Observed Adverse Effects Level (NOAEL) for the mink while the 1.0 ppm represents the Lowest Observed Adverse Effects Level (LOAEL) for the Heron.

RAOs/Project objectives: The remedy consisted of three primary RAOs:

- Protect human health and the environment from imminent and substantial endangerment due to PCBs attributed to the site. To achieve this remediation objective, PCB-contaminated soft sediment will be removed so that the entire river will reach an average PCB sediment concentration of 0.5 ppm or less over time. An average PCB sediment concentration of 0.5 ppm results in an excess human health carcinogenic risk of 1.0×10^{-4} or less over time through the consumption of PCB-contaminated fish. Based on site-specific biota to sediment accumulation factors, the corresponding PCB tissue level of resident fish are:

Sport Fish	Bottom Feeders
Small Mouth Bass: 0.31 ppm	Carp: 2.58 ppm
Walleye: 0.63 ppm	Catfish: 2.53 ppm
Trout: 0.09 ppm	

- For PCB-contaminated floodplain areas, this remediation objective will be achieved by removing sufficient contaminated soil to reach an average PCB soil concentration of 10 ppm or less.
- Mitigate potential PCB sources to the Sheboygan River/Harbor system and reduce PCB transport within the river system.

Remove and dispose of Confined Treatment Facility/Sediment Management Facility sediments and previously armored/capped PCB-contaminated soft sediment deposits.

A.64.5 Remedial Approach

Final selected remedy: Removal and MNR

Remedy Contained in two separate documents Record of Decision (ROD) and Explanation of Significant Difference (ESD)

ROD May 2000

Upper River sediment removal of approximately 20,774 yd^3 of PCB-contaminated sediment to achieve a removal of 88% of PCBs mass from soft sediment. Conduct fish and sediment sampling to document natural processes and ensure that over time the entire river will reach an average PCB sediment concentration of 0.5 ppm or less. Middle River sediment characterization combined with Upper River conditions to achieve a soft sediment SWAC of 0.5 ppm overall in the Upper and Middle River. Conduct fish and sediment sampling to document natural processes and ensure that over time the entire river will reach an average PCB sediment concentration of 0.5 ppm or less.

Lower River sediment characterization, removal of sediment if necessary to achieve a soft sediment SWAC of 0.5 ppm in the Lower River, annual bathymetry surveys to identify areas susceptible to scour, and fish and sediment sampling to document natural processes and ensure that over time the entire river will reach an average PCB sediment concentration of 0.5 ppm or less.

Inner Harbor sediment characterization, removal of approximately 53,000 yd^3 of PCB-contaminated sediment to achieve a SWAC of 0.5 ppm in the Inner Harbor, annual bathymetry surveys to identify areas susceptible to scour, fish and sediment sampling to document natural processes and ensure that over time the entire river will reach an average PCB sediment concentration of 0.5 ppm or less.

Removal of floodplain soils containing PCB concentrations above 10 ppm. Investigation and mitigation of potential groundwater contamination and possible continuing sources at the former

Tecumseh Plant in Sheboygan Falls. Placement of institutional controls (ICs) to limit access to Tecumseh's Sheboygan Falls Plant groundwater as a drinking water source.

Explanation of Significant Difference (ESD) December 2010

The ESD adjusted the volume of contaminated sediment to be removed from the river, the areas from which those sediments will be removed and the cost of the modified remedy, as a result of the pre-design characterization effort and remedial design for the Lower River and Inner Harbor portion of the remedy.

This modification to the selected remedy set forth in the ROD does not fundamentally alter the basic features of the selected remedy with respect to scope, performance, or cost. The modification provides for the implementation of the remedy for the Lower River and Inner Harbor at the Site in a way that will address the most contaminated PCB soft sediment vulnerable to recreational and natural disturbances in order to achieve the 0.5 ppm SWAC in both reaches over time. Consistent with the Remedial Investigation, a soft sediment deposit shall be defined as an area containing a soft sediment depth of 1 ft or greater as determined by probing.

	May 2000 ROD **Contaminated Sediment Volume to be Removed**	**Lower River Remedial Design Contaminated Sediment Volume to be Removed**
Lower River	None	16,158 yd^3
Inner Harbor	53,000 yd^3	34,390 yd^3
Total Volume of Contaminated Sediment to be Removed from the Lower River and Inner Harbor		50,548 yd^3

Advantages of the selected remedy:

- Permanent, long term solution
- Mass removal of PCBs

Disadvantages of the selected remedy:

- PCBs will still be available at sediment/water interface for fish to bioaccumulate
- Fish tissue concentrations will require lengthy recovery timeline
- Remedy is complex

Expected recovery time: 19 years.

A.64.6 Monitoring

Monitoring elements: Monitoring will occur under the 5 year review which will take place within 1-2 years. No plan has been designed yet.

RAOs/project objectives achieved: Upper River mass removal at 88% was achieved. Sediment removal is ongoing in other portions of the river and harbor.

A.64.7 Costs

Net present value for project costs: Upper River $23,800,000; Lower River and Inner Harbor $10,000,000; Floodplain soil $4,500,000; and Groundwater investigations and source control $600,000 (discounted by 7 percent per year for the estimated life of the project)

A.64.8 References

Declaration for the Record of Decision Sheboygan River and Harbor. http://www.epa.gov-/region05/cleanup/sheboygan/pdfs/sheboygan_rod_200005.pdf.

Consent Decree for the Lower River Work on the Sheboygan River. http://www.epa.gov-/region05/cleanup/sheboygan/pdfs/sheboygan_cd_2011.pdf.

Administrative Order on Consent for Remedial Design for the Lower River Portions of the Rod. http://www.epa.gov/region05/cleanup/sheboygan/pdfs/sheboygan_aoc_200902.pdf.

Explanation of Significant Differences. http://www.epa.gov-/Region5/cleanup/sheboygan/pdfs/sheboygan_esd_201012.pdf.

A.65 Sapp Battery, Jackson County, FL

Sapp Battery Salvage, FL

A.65.1 Contacts

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A.65.2 Summary

Environment:	Wetlands
Scale:	Full
Contaminants of Concern:	Lead
Final Remedy:	Removal

A.65.3 Site Description

The Sapp Battery Site occupies an area of approximately 45-acres in Jackson County, Florida. The site is bisected by Jackson County Road 280 and is located immediately adjacent and west of the Atlanta and St. Andrews Bay Railroad Tracks. The site includes swamp areas on the north and south sides of County Road 280.The primary source of contamination at this site was past direct discharges of battery acid to the ground.

In 1970, Sapp Battery Service, Inc. initiated battery recycling and salvaging operations at the site. The primary operating areas of the site were on the north side of County Road 280.

The business, at its peak, processed about 50,000 used batteries per week. Standard Operating Procedures during the battery salvaging operations were to dump the acid from the batteries outside the plant, where it ran southeast into the west swamp that drained to the East and Southeast swamps, under County Road 280 and eventually into Steele City Bay on the south side of County Road 280.

By 1977 the acid discharge from the plant started to kill cypress trees in Steel City Bay and beyond. It was determined that the acid runoff from the plant carried significant levels of lead-containing sediments into the swamp areas including Steele City Bay.

The company took several steps to try to alleviate the problem in response to enforcement actions. A large holding pond for acid wastewater was excavated directly south of the facility, fill material obtained from the holding pond was used to construct a berm south of the West Swamp, and a channel was dredged to connect the West and East swamps. The measures failed and operations ceased in 1980, and the site was abandoned.

The site was added to the National Priorities list in 1982. A feasibility study was completed in 1986 and a Record of Decision was signed in September 1986.

Remedial investigations confirmed the presence of lead containing sediments in the Steele City Bay.

The levels of total lead contamination have been found to range from 0 to 8,000 mg/kg. The primary operating areas of the site on the north side of County Road 280 were remediated in 1999-2000.

CSM summary: Surface water from the Sapp Battery operating area either flowed into the Northwest Swamp, into the West Swamp, or through the West culvert under County Road 280 directly into Steele City Bay. From West Swamp, the water naturally flowed to the East Swamp and then the Southeast Swamp, through the East culvert under County Road 280 and into Steele City Bay.

A.65.4 Remedial Objectives

In order to remove contaminated sediments from selected wetland areas and portions of Steele City Bay, lily pad root mass and other wetland features will have to be removed in order to address sediment bound in root mass or to tree roots.

RAO(s)/Project objectives: The primary objective of this project is to remove lead contaminated sediments from approximately 15 acres of wetland areas and Steele City Bay where lead concentrations were found to exceed 200 mg/kg.

A.65.5 Remedial Approach

Final selected remedy: Removal

The final remedy targets the contaminated sediments that exceed 200 mg/kg in Area A north of County Road 280, Areas C&G south of County Road 280 and Steele City Bay. The areas were cleared and dewatered to allow access for the removal. Access roads were constructed using imported fill. Conventional excavation means and transport were used along with sediment control structures. For Area A the excavation was planned over a 5-acre area to a depth of 2 ft. The excavation in Areas C&G and Steele City Bay was to cover approximately 10-acres to a depth of 2 ft.

Removal was selected because sediment was bound up in the root mass of the lily pads and tightly adhered to the tree stumps, tree roots, and fallen trees in both of the wetland areas. In order to remove the lead contaminated sediment these had to be cleared and the physical separation of the contaminated sediment without removing the lily pad root mass, tree stumps, roots and fallen trees was not cost effective.

Other alternatives reviewed but not selected included:

- use of specialty flotation excavation and transport equipment to excavate the sediment from under water without dewater the wetlands or bay.
- excavation of the sediments from under the water without removing any surface water followed by hydraulic dredging with a floating barge-type cutter head dredge.

A.65.6 References

USEPA Region 4 Superfund, Sapp Battery Salvage Web Site last updated June 27, 2014. http://www.epa.gov/region4/superfund/sites/npl/florida/sapbatfl.html.

A.66 Shiawassee River, MI

A.66.1 :

Shiawassee River Superfund Site, Howell, Michigan

A.66.2 Contacts

Regulatory Contact: Michigan DEQ & USEPA
Site Contacts: Daria Devantier, Michigan DEQ and James Hannenberg, USEPA Region 5

A.66.3 Summary

Environment:	Plant site on the Shiawassee River
Scale:	Limited removal to facilitate MNR
Contaminants of Concern:	PCB oils
Source Control Achieved Prior to Remedy Selection?	Original remedy: Limited removal at the plant site, subsequently determined high level of PCB in the sediments and fish of the Shiawassee River.
Final Remedy:	Removal and MNR. Hot spot removal and limited excavation; used reduced concentrations using SWAC to justify the decision. Long term monitoring to assess whether reductions are occurring.
Expected Recovery Time:	To be determined (concentrations currently increasing and results ambiguous)
MNR viewed as a success?	No. Poor design, poor characterization. And inappropriate use of the SWAC method appears to be problems at this site. Successive sampling by USEPA after the removal in pre-designated areas have found increasing concentrations of PCB. State of Michigan investigation after the removal found higher levels of PCB in areas not addressed by the removal. Greater areal extent, as well as concentration, were verified overall in the river after the removal had been completed. The limited design assumptions and removal are therefore being questioned. Monitoring of residual contamination and assessment of sediment rates are ongoing.

A.66.4 Site Description

Since 1969, the Cast Forge Company (CFC) and now Western Wheel have manufactured aluminum cast products in Howell, Michigan, at the CFC facility. Until 1973, wastewater contaminated by hydraulic fluids containing polychlorinated biphenyls (PCBs) was discharged by the potentially responsible parties to the South Branch of the Shiawassee River. From 1973 to 1977, wastewater was discharged into a 400,000 gallon on-site lagoon. Discharges from this lagoon as well as periodic overflows have contaminated nearby wetlands and, subsequently, the Shiawassee River. In 1978 and 1979, the state detected high levels of PCBs in soils around the site and in on-site monitoring wells. Concentrations above one part per million (ppm) were found in Shiawassee River sediments fourteen miles downstream of the plant.

The United States Environmental Protection Agency (EPA) proposed the site for the National Priorities List (NPL) in December 1982 and finalized the site on the NPL in September 1983.

A removal action, very strategically designed with the intent of reducing the concentration of PCB in the river to levels that would "eventually" allow the river to naturally recover was the basis for the removal action that was undertaken on a segment of this river.

There were serious questions about the characterization, statistical manipulation of the characterization data to calculate the removal quantities, and the collection and analyses of data to determine whether the limits of excavation were appropriate when the removal action was ongoing. Confirmation data was also questionable when the removal action moved from one segment of the river to the next.

A more thorough analyses and sampling of the river was conducted after the removal in order to evaluate the potential for the removal action to be successful. This led to the discovery of much greater concentrations of PCB and confirmed a more extensive problem when post removal data were interpreted.

Subsequent monitoring of the effectiveness of the removal indicates that natural recovery is not working. In fact, levels appear to be increasing and trends are up. This evaluation process however is ongoing and USEPA has indicated that the removal "may" not have been effective enough to assure natural recovery.

Concentrations of PCB in the Shiawassee River sediment were found to require removal due to fish tissue studies. Natural recovery was postulated as a remedy if selected "hot spots" were removed in order to reduce the influx to the river.

Subsequent independent sampling after the removal uncovered more extensive contamination and far greater concentrations in hot spots than the RI based design and statistical evaluation anticipated.

Post excavation monitoring by USEPA has caused them to acknowledge the success of this remedy is currently questionable. A few more rounds of sampling are anticipated necessary before the agency will further evaluate the meaning of the "currently" increasing trends and the redistribution of PCB contaminant in sediments.

The State of Michigan has authorized this site as a potential case study.

The primary source of contamination at this site was on-site loss of PCB oils and the discharge of PCB oil contaminated waste to the treatment lagoons. Overflow and loss of lagoon contents directly to the Shiawassee River were the primary contamination mechanism.

In November 1977, the State filed suit against Cast Forge for PCB-contamination of the environment. The case was settled through a consent judgment in June 1981. Under that settlement, the company removed the lagoon, cleaned up PCB-contaminated soil and sediment from its property, and provided $750,000 for restoration of the Shiawassee River. Dredging of the South Branch of the Shiawassee River began in June 1982. Only the first mile downstream from the plant was vacuumed, removing approximately 2,600 pounds of PCBs, before the funding was exhausted. Both the site property and river still contain PCBs.

The State began a Remedial Investigation and Feasibility Study (RI/FS) in September 1986. Field sampling activities were started in October 1987 and completed in November 1989.

The RI report was finalized in January 1992. The FS report, which evaluated various cleanup alternatives, was submitted in December 1997, and a proposed cleanup plan was released to the public in August 1998. Because the data used to develop cost estimates were obtained as long ago as 1986, it was determined that additional data should be obtained to develop more accurate cost estimates for the site.

Additional sampling of the site began in November 1999 and was completed in April 2000. These sample data were released to the public in a data evaluation report in May 2000. The supplemental FS report was released in early 2001, and USEPA issued a Record of Decision (ROD) on September 28, 2001. The ROD selected the floodplain and contaminated areas near the Cast Forge facility to be remediated to less than 10 ppm PCBs. The river was to be remediated to less than 5 ppm PCBs for the first mile downstream of the facility. Remediation was completed in 2005, meeting all ROD requirements.

USEPA issued the First Five-Year Review Report for the site on August 27, 2009. The review concluded that the remedy is protective of human health in the short term, as exposure pathways that could result in unacceptable risks to humans are currently being controlled. However, in order for the remedy to be protective in the long term, comprehensive monitoring data needs to show that PCB concentrations are decreasing in accordance with the expectations described in the 2001 ROD. The five-year review concluded that additional comprehensive sampling is needed to determine whether the remedy is functioning as intended; comprehensive monitoring is scheduled for 2012 as indicated in the 2001 ROD. Finally, USEPA and the state may evaluate the effectiveness of existing fish advisories.

CSM summary: The Shiawassee River was contaminated by losses of PCB oils directly into the river and through dissolved and waste lagoon discharges. The PCB oils attached to sediments and particulates as well as organics. Once entrained in the river system, they settled with the particles and were bio available in the upper portions of the sediment column. Fish and aquatic organisms became contaminated with PCB, and levels were sufficient to warrant fishing advisories for the river. The wastes are continuously redistributed due to the annual fluctuations in flood stage and fluvial geomorphology dynamics.

A.66.5 Remedial Objectives

The risks posed at the site are to human health through direct contact in some areas and human health and environmental damage through bioaccumulation of PCB in fish and aquatic life.

RAO(s)/Project objectives: The remedial action objective is to protect human health and the environment from imminent and substantial endangerment due to PCBs attributed to the site. To achieve this remediation objective, the ROD called for PCB-contaminated sediment above 5 mg/kg to be removed so that the five-mile reach of the river beginning at M-59 would reach an average PCB sediment concentration of approximately 1 mg/kg (which is equivalent to 1 ppm) immediately after active remediation; the ROD then called for monitored natural recovery over time to achieve the long-term preliminary remediation goals (PRGs). The long-term PCB PRG range for the Shiawassee River sediment, 0.003 to 0.2 mg/kg, is based on protecting mink through dietary consumption of fish. The ROD estimated that it would take 18 years and 7 years, respectively, to attain these long-term goals by natural recovery processes.

A.66.6 Remedial Approach

Final selected remedy: The remedy selected in the 2001 ROD required excavation and off-site disposal of PCB contaminated soils and river and floodplain sediments, and that institutional controls be placed on the CFC property to ensure that it remained zoned for industrial use. Therefore, the following actions were taken from November 1, 2004 to August 15, 2005:

- Excavation of 154 yd^3 of PCB-contaminated soils at CFC and disposal off-site.
- Excavation and off-site disposal of 160 yd^3 of PCB contaminated floodplain soil at four different locations.
- Removal and off-site disposal of 50 yd^3 of PCB-contaminated river sediments.

A total of 364 yd^3 of PCB contaminated sediments and soils were excavated.

Removal of contaminated sediments and the volume calculated to excavate were based on SWAC estimates.

Why the remedy was selected: The remedy was selected based upon unacceptable risk to human health and the environment. Multiple completed risk based pathways were confirmed for a multitude of on-site and off-site contaminants. Bioaccumulation of DDT and ongoing losses from the site that included a number of highly toxic aquatic contaminants caused the selection of containment and sediment removal to alleviate exposure threats.

Primary lines of evidence used to investigate MNR: MNR will take some time to determine whether it is working. Preliminary data do not indicate the removal was successful. Higher concentrations were found in sediment than prior to the excavation.

Expected recovery time: The long-term PCB PRG range for the Shiawassee River sediment, 0.003 to 0.2 mg/kg, is based on protecting mink through dietary consumption of fish. The ROD estimated that it would take 18 years and 7 years, respectively, to attain these long-term goals by natural recovery processes. These estimates were based upon characterization data that may not properly present the volume of contaminant. This dynamic needs further evaluation.

A.66.7 Monitoring

Following completion of the remedial action construction activities in 2005, annual monitoring was conducted in August 2006, July 2007, and August 2008, with each sampling event consisting of 30 samples of PCB contaminated river sediments. These results are presented in a report by ENTACT LLC, entitled Sediment Summary Report for the Shiawassee River Superfund Site, prepared for Johnson Controls, Inc., May 26, 2009 (ENTACT Report). Additionally MDEQ completed sampling and analysis in 2006 and early 2007, with the results presented in a report by Gannett Fleming (for Michigan Department of Environmental Quality, Remediation and Redevelopment Division), entitled Technical Memorandum for the Fourth Phase of the Remedial Investigation Activities at the South Branch of the Shiawassee River, Howell, Michigan, and dated December 2008 (MDEQ Report). The data collected to-date are further discussed below.

Monitoring elements:

Annual monitoring is currently planned to be conducted on an annual basis, with a comprehensive monitoring event currently scheduled for 2012. Monitoring requirements after 2012 will be determined after evaluating the data from the comprehensive monitoring event.

RAOs/project objectives achieved?

Too soon to evaluate, but preliminary data would indicate there may be a problem since data collected after the removal found higher contamination in areas of the river than was considered by the designed removal. Characterization and design assumptions should therefore be questioned and evaluated. The assumptions and spatial variation of samples used to generate the SWAC estimates for removal volumes were also questionable.

A.67 St. Lawrence River, NY

A.67.1 Summary

Environment:	Freshwater
Scale:	Field
Contaminants of Concern:	PCBs: 0.04-10,000 ppm before dredging
Final Remedy:	Hydraulic dredging. Some boulders pulled up were power washed and added to shore reconstruction. Sediment with concentrations >10ppm were transported by rail, 2190 miles to Tooele, UT. The remaining sediment was put in a lined on-site landfill.

A.67.2 Site Description

GM Massena Hydraulic dredging

St. Lawrence River near shore flow rates up to 2.0 fps.

Year: 1995

Water Depth: 0–30 ft

Target Volume: 29,000 yd^3

Actual Volume Removed: 13,800 yd^3

A.67.3 Remedial Objectives

PCBs: 1 ppm

Contaminated sediment area: 11 acres, 2,500-foot long near shore area in the St. Lawrence River

A.67.4 Remedial Approach

Some boulders pulled up were power washed and added to shore reconstruction.

A.67.5 Monitoring

Resuspension:

Silt curtains tried for containment, but were unable to withstand river currents. Redesigned system consisted of interlocking steel sheet pile panels enclosing dredged area reducing potential for off-site migration.

Residuals:

Postdredging concentrations were met in all but one of the six divided regions. That one region was backfilled with clean sand to meet the cleanup goal.

A.67.6 References

USEPA. Realizing Remediation II an Updated Summary of Contaminated Sediment Remediation Activities at Great Lakes Aras of Concern. July 2000. http://www.epa.gov-/glnpo/sediment/realizing2/RR2report.PDF.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.68 Starkweather Creek, WI

A.68.1 Summary

Environment:	Freshwater
Scale:	
Contaminants of Concern:	Mercury: 1.1 ppm (3.5 ppm max) Lead: average 130 ppm Chromium: 19 ppm Oil and Grease: 2,800 ppm
Final Remedy:	Dredged wet with conventional backhoe. Removed sediment was transported by truck to a sediment retention and dewatering facility 6 miles from site where it was dewatered and disposed.

A.68.2 Site Description

Year: 1993

Water Depth: 1.5 ft, maximum 2 ft

Target Volume: 17,000 yd^3

Actual Volume Removed: 15,000 yd^3

A.68.3 Remedial Objectives

None selected, mass removal of mercury and other metals

Contaminated sediment thickness: average 4 ft (7 ft max)

Contaminated sediment area: 1 mile long, 50 ft wide

Dredge depth: up to 7 ft

Another target was to increase average depth of creek channel from 1.5 to 4 ft and max depth from 2 to 7 ft.

A.68.4 Remedial Approach

Dredging was done as wet excavation with a conventional backhoe. Water monitoring happened weekly, visual observations of turbidity changes were made daily.

A.68.5 Monitoring

Resuspension:

Breaking cleanup into sections minimized resuspension. Double silt curtain placed across creek downstream from construction. Curtains held in place at top by steel cable tied to trees and bottom by logging chain. Testing past silt curtains after dredging found contaminant levels low to background.

Performance:

Goals seem to have been reached.

Residuals:

No capping or backfilling were needed at this site. No MNR, but reestablishment of creek habitat did take place.

A.68.6 References

Water Resources Management Practicum 2005. Starkweather Creek Watershed: Current Conditions and Improvement Strategies in an Urban Context. 2006. Nelson Institute for Environmental Studies University of Wisconsin. http://www.nelson.wisc.edu/docs/report.pdf.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.smwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.69 Stryker Bay, Duluth, MN

A.69.1 Contacts

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A.69.2 Summary

Environment:	Lake bay
Scale:	Full
Contaminants of Concern:	PAH compounds, metals (As, Cd, Cr, Cu, Pb, Hg), coal tar NAPL
Source Control Achieved Prior to Remedy Selection?	Yes, historical industries are closed.
Final Remedy:	amended capping (11 acres), dredging (22 acres)

A.69.3 Site Description

Primary source(s): Likely wastewater discharges from the water gas, coking, and tar facilities formerly located on the SLRIDT site.

Location: Stryker Bay is a shallow, flat-bottomed bay of approximately 41 acres with average water depth of approximately 3 to 5 ft. There are homes to the west and industrial land to the north and east. A wetland is located at the north end where an unnamed stream enters the bay from a steep urban watershed, and another wetland is located in the southwest corner near the mouth of the Bay.

The SLRIDT site has been used for industrial purposes since at least the 1890s. Prior to industrialization, the SLRIDT site was predominantly open water and was part of St. Louis Bay, bounded on the west by 63rd Avenue Peninsula.

Coke production began in 1904. A water (town) gas manufacturing plant operated intermittently from 1905 to 1961. Tar refining began in 1905 and operated at multiple sites until 1948. The most recent iron plant has not operated since about 1960.

Industrial byproducts were used in conjunction with re-deposited native sediment as fill to create new land, including the 59^{th} Avenue Peninsula and the 54th Avenue Peninsula. The primary fill material is slag from on-site pig iron operations.

CSM summary: Numerous processes act on the groundwater/sediment/surface water interface in Stryker Bay including: upward advection (flow) of groundwater and downward flow of surface water into the sediment, diffusion of chemicals from the sediment to the water, new sediment deposition, bioturbation (mixing of sediment by organisms), biodegradation, mixing, and redistribution from bed shear induced by waves, prop wash, currents, and occasional anchoring. Within the bay, ice usually freezes to the bed around the perimeter and thaws in place. Some of these processes deliver PAHs to the surface; others dilute, degrade, and physically redistribute the PAHs.

A.69.4 Remedial Objectives

Remediation risks at this site include adverse effects to public health, aquatic plants and animal community from mobilization of organics and metals from sediment.

RAO(s)/Project objectives:

- Sediment cleanup levels:
    - TPAH concentration must not exceed 13.7 mg/Kg
    - Mercury must not exceed 0.3 mg/Kg
    - Other metals (As, Cd, Cr, Cu, Pb, Ni, and Zn) 0.6 times the mPEC-Q based on Level 2 SQTs

- Dredged sediment water must be treated on site to meet MPCA surface water discharge standards prior to discharge to river.
- During remedy, ambient air naphthalene concentration in residential area must not exceed 2,000 $\mu g/m^3$.

A.69.5 Remedial Approach

Final selected remedy: amended capping (AC Reactive Core Mat™) and dredging.

The selected remedy consists of a combination of in situ amended capping, environmental dredging, dredged sediment containment and institutional controls. Sheet piling separated dredge area from cap area. Dredged material was pumped to CAD for settling. Supernatant water from CAD was treated by wastewater treatment train of sand filter, organoclay media, AC media, and micron bag filter. Capping consisted of following sequence:

1. Place 6” sand over sediments.
2. Place AC Reactive Core Mat™.
3. Place 3.5’ sand cover and 4.5-6.5’ surcharge load over RCM.
4. After consolidation, remove surcharge sand to cap dredged sediment CAD.

Why the remedy was selected: Air modeling indicated that if the areas of the bay with sediment naphthalene concentrations > 1,000 mg/kg were dredged, that ambient air quality criteria in the neighboring residential area would be exceeded. So in these areas, capping was used instead of dredging. Modeling of contaminant transport upward into the in situ cap predicts that the cap would be effective in preventing contaminants from exceeding RAOs and Cleanup Levels in the BAZ and surface water in the long-term. In addition to a conventional sand cap, AC Reactive Core Mat™ was inserted in the design as an additional factor of safety.

A.69.6 Monitoring Approach

The agencies and PRPs are finalizing the details of a 5-year performance monitoring plan. Performance monitoring will consist of three elements:

- pore-water monitoring
- bulk sediment monitoring
- benthic community uptake monitoring for PAHs and mercury

RAOs/project objectives achieved? Air monitoring objectives were met during construction.

A.69.7 Costs

The 22 acres of dredging and the 11 acres of capping cost an estimated $32 million. The Reactive Core Mat™ active cap material cost was approximately $1 million. Relocation of Slip 6 dock to allow conversion to a CAD for dredged material disposal cost an additional $12 million.

A.69.8 Advantages and Limitations

Site Specific Challenges:

- Regulatory—Communication with numerous local, state, and federal agencies through The Metropolitan Interstate Committee's Harbor Technical Advisory Committee.
- Technical—Air modeling indicated that if the areas of the bay with sediment naphthalene concentrations > 1,000 mg/kg were dredged that ambient air quality criteria in the neighboring residential area would be exceeded. Hybrid dredge/cap remedies were evaluated that alleviated the air quality concerns.
- Community—The community stakeholders actively participated in the process that led to the identification of new hybrid remedies involving mixes of dredging, capping and containment technologies.

Acceptance: Based on the comments received by the MPCA during the public comment period on the Proposed Plan, there was in general high support for this alternative. Reasons cited for support of this alternative included maintaining natural resources and maintaining riparian use for property owners in the Stryker Bay. Concerns for this alternative included leaving the contamination in the water, long term protection of public health, and the environment and financial assurances in the event that the remedy fails. Based on these comments, the MPCA has added O&M, monitoring, contingency action plans, and financial assurance to the final ROD.

A.69.9 References

Minnesota Pollution Control Authority, Record of Decision for the Sediment Operable Unit of the St. Louis River/ Interlake/Duluth Tar Site, Duluth, MN, August 2004. http://www.pca.state.mn.us/index.php/view-document.html?gid=3222 Accessed December 15, 2011.

A.70 Sullivan's Ledge, MA

A.70.1 Summary

Environment:	Brackish marsh areas
Scale:	
Contaminants of Concern:	PCBs, PAHs
Final Remedy:	Removed sediment with backhoes and long reach excavators and trucked dredged material to treatment pad on site for stabilization. This included an addition of 20% lime kiln dust by volume and up to 10% sand by volume then mixed. Contaminated material was capped on site.

A.70.2 Site Description

Year: 2001

Estimated debris content of 40-80% in OU 1.

OU 2 wetlands are within a 25- and 100- year floodplain of unnamed stream.

Actual Volume Removed: 35,200 yd^3 in OU 1 and OU 2

A.70.3 Remedial Objectives

15 mg/kg total PCBs

Contaminated sediment area:

OU 1: 12 acres of disposal area, unnamed stream, and 2 golf course water hazards

OU 2: 7 acres of wetland

A.70.4 Remedial Approach

Backhoes and long-reach excavators were used for dredging.

A.70.5 Monitoring

Resuspension:

Silt fencing was used for erosion control. Air monitoring to ensure no suspension of contaminants.

Performance: Goals were not met.

Residuals:

The sediment cleanup criterion was determined to be impractical following review of initial confirmation sample results.

A.70.6 References

New England Environmental, Inc. 10-Acre Wetland Restoration Sullivan's Ledge Superfund Site New Bedford MA. http://www.neeinc.com/projects/ecological-restoration/sullivans-ledge-superfund-site/.

USEPA. Five-Year Review Report for Sullivan's Ledge Superfund Site. Sep 2003. http://www.epa.gov/superfund/sites/fiveyear/f03-01009.pdf.

USEPA. Second Five-Year Review Report for Sullivan's Ledge Superfund Site. Sep 2008. http://www.epa.gov/superfund/sites/fiveyear/f2008010002480.pdf.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.71 Ten-Mile/Lange/Revere Canal, MI

A.71.1 Summary

Environment:	Freshwater
Scale:	
Contaminants of Concern:	Heavy metals, VOCs, SVOCs, TMD system: ND - 121,000 ppm PCBs Sanitary Sewers: 3.9-48 ppm PCBs Catch Basins: 02-28.5 ppm PCBs
Final Remedy:	TMD System: isolating 20–30 ft sections at a time, using "pillow plugs," then removed water. Canal dewatered using metal sheet-piling. Contaminated sediment was stabilized with bentonite-polymer mixture. Off-site disposal: 5,915 tons sent to Wayne Disposal (Belleville, MI): 41 miles. 18,315 tons sent to Lenox, MI: 25 miles. Canal soils sent to USACE Point Mouillee, MI.

A.71.2 Site Description

St. Claire Shores, MI

Year: 2003

Water Depth: 12–18 ft

Actual Volume Removed: 24,230 tons

A.71.3 Remedial Objectives

Remove all sediment >1 ppm PCBs.

Contaminated sediment thickness: 3 ft.

Contaminated sediment area: entire length (4,400 ft.) of pond

A.71.4 Monitoring

Resuspension:

Silt curtains were used to contain contaminated sediment and to reduce/control turbidity.

Performance:

All sediment areas were below the 1 ppm goal.

Residuals:

No capping or backfill was necessary for this site.

Three sampling areas:

TMD: Ten-Mile Drain

Sanitary Sewers (no remediation)

Catch Basins

Limited dredging action around boat slips later in 2004

A.71.5 References

USEPA Ten-Mile Drain System and Ten-Mile/Lange/Revere Canal PCB Cleanup. Nov 2002. http://www.epa.gov/region05/cleanup/tenmiledrain/.

Agency for Toxic Substances & Disease Registry Health Consultation Response To Public Comments as updated Nov 2009. http://www.atsdr.cdc.gov/hac/pha/pha.asp?docid=463&pg=1.

Weston Solutions, Inc. Bon Brae/Harper Site Removal Action St. Clair Shores, Macomb County, Michigan Technical Direction Document No: S05-0001-0912-017. Jun 2010. http://www.epa.gov/region5/cleanup/tenmiledrain/pdfs/tmd_ra_2011.pdf (Weston, 2010).

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.72 Tennessee Products, TN

A.72.1 Summary

Environment:	Freshwater
Scale:	Full
Contaminants of Concern:	PAHs
Final Remedy:	Earthen dams, with water pumped around by three 12-inch pumps. Long Stick Excavator was used to dredge material Contaminated sediment mixed with drying agent and trucked to off-site disposal facilities; cement kiln in South Carolina, a boiler in Baldwin, Illinois, and another cement kiln in Tennessee.

A.72.2 Site Description

Year: 1998

Water Depth: 0–4 ft

Target Volume: 5,000 yd^3

Actual Volume Removed: 23,300 yd^3

A.72.3 Remedial Objectives

Visually-identified coal tar material and disposal pit in the floodplain are targets.

Contaminated sediment area: 2.5 miles of Chattanooga Creek (50-75 ft wide)

A.72.4 Remedial Approach

Long-stick excavator was used. NAPL site was found during excavation and was capped with AquaBlok. Two methods of dewatering were used before they were discarded for earthen dams (flume tubes and Port-A-Dams).

A.72.5 Monitoring

Resuspension:

There are no resuspension controls needed at this site because dry excavation was used.

Dredge depth was generally 3-6 ft; however, one hole was dredged 15 ft deep.

Residuals:

There was no capping or backfilling needed for this site except for one NAPL site found during excavation.

Still monitoring AquaBlok cap of NAPL site at this time.

A.72.6 References

EPA Superfund Explanation of Significant Differences: Tennessee Products EPA ID: TND071516959. Aug 2004. http://www.epa.gov-/superfund/sites/rods/fulltext/e0404091.pdf.

TDEC-DoR. First Five-Year Review Report for Tennessee Products Superfund Site EPA ID# TND071516959. Sep 2011. http://www.epa.gov-/superfund/sites/fiveyear/f2011040004115.pdf.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.73 Terry Creek, GA

A.73.1 Summary

Environment:	Freshwater
Scale:	Full
Contaminants of Concern:	Toxaphene-Outfall Ditch Max: 2,600-30,000 ppm North Dupree Creek Max: 290 ppm Confluence Area Max: 110 ppm
Final Remedy:	A cable arm environmental clamshell bucket was used. Removed material was retained in drain beds for six months to dry. Dried contaminated sediment was sent off site to Savannah, Georgia, 78 miles.

A.73.2 Site Description

Three removal areas:

- Outfall Ditch
- North Dupree Creek area
- Confluence area

Year: 2000

Target Volume: 26,000 yd^3

Actual Volume Removed: 35,148 yd^3

A.73.3 Remedial Objectives

Mass removal of toxaphene: target depth 1-8 ft in Outfall Ditch and 1-6 ft everywhere else.

A.73.4 Remedial Approach

A cable arm environmental clamshell bucket was used.

Three removal areas:

Outfall Ditch

North Dupree Creek area

Confluence area

A.73.5 Monitoring

Resuspension:

Sheet piling dike installed around perimeter of Outfall Mouth removal areas to minimize run-in of adjacent creek sediment due to required 5 ft excavation and to aid in controlling migration of sediment outside removal area.

Silt curtains for containment.

Air and water samples taken to ensure contamination did not disperse.

Residuals:

Technically no numerical goal numbers hit. Decided removal was adequate based on post-removal concentrations.

Post dredging concentrations:

Median: 4.5 ppm

Max: 2,700 ppm toxaphene

Sampling was done inside and outside of silt curtains to ensure resuspension measures were successful.

A.73.6 References

Agency for Toxic Substances & Disease Registry Public Health Assessment Terry Creek Dredge Spoil Areas/Hercules Outfall Site Brunswick, Glynn County, Georgia as updated Mar 2010. http://www.atsdr.cdc.gov/hac/pha/pha.asp?docid=1030&pg=1 (ATSDR).

USEPA Region 4: Superfund Terry Creek Dredge Spoil Area/Hercules Outfall as updated Jan 2012. http://www.epa.gov/region4/superfund/sites/npl/georgia/tcredrespoga.html.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.smwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.74 Torch Lake, MI

Torch Lake Superfund Site

A.74.1 Contacts

Regulatory Contact: Michigan DEQ & USEPA
Site Contacts: Scott Cornelius Michigan DEQ and Tom Alcamo USEPA Region 5

A.74.2 Summary

Environment:	Lake
Scale:	Full
Contaminants of Concern:	Very large list: Multiple heavy metals, PAH, PCB, phthalates, coal tars, nitrates, ammonia compounds, processing waste from explosives manufacturing
Source Control Achieved Prior to Remedy Selection?	Original remedy: Vegetative and soil capping of stamp sands. No control of industrial processing facilities, no attention to heavy metal and sludge discharges directly to the lake, no investigation of PCB sources, and insufficient characterization of waste disposed in Torch Lake. Extreme hot spots discovered in lake but not dealt with in administrative document.
Final Remedy:	Capping of the Stamp Sands, institutional controls to prevent cap damage, monitoring of the lake to assess MNR recovery
Expected Recovery Time:	Currently estimated to be 850 years or more due to increasing heavy metals at the sediment water interface
MNR viewed as a success?	Yes, but only moderately. The massive erosion and windblown sand has decreased dramatically. Inhalation of heavy metal dust and human exposure has been decreased. Torch Lake, however, shows increasing heavy metal contamination regardless of the decrease in erosional input of heavy metal rich sands. Other critical and significant human health and environmental inputs to the lake have not been acknowledged or investigated and no action has been taken to include the concerns in the ongoing evaluation of the remedy by USEPA. Evidence of massive residual contamination in the region that can serve as an ongoing source to the lake has been demonstrated conclusively and documented with formal reports.

A.74.3 Site Description

This site is located in the copper mining district of the Upper Peninsula of Michigan. It is located in the Keweenaw Peninsula of Michigan. Extensive processing of copper ore occurred all around the shores of Torch Lake. Chemical leaching of copper, dredging of stamp sands for reprocessing, and intense heavy metal liberation into the ecosystem has occurred.

The ROD was not based on an adequate RI and many of the conceptual site model assumptions used for decision making at the time of the ROD are now proven to be inappropriate. The assumption was that natural recovery would allow the lake to improve, and the highly toxic metal concentrations as well as organic and other coal tar and other complex long chain hydrocarbons would be removed from contact with the ecosystem. It has been determined that the metals concentrations in the sediment at the surface are increasing, not diminishing. The geochemistry and contaminant transport are apparently far different than what the site conceptual model anticipated. So much so that it now appears it will take hundreds of years (the study indicated at least a number above or below 850 years). There are extensive reports, studies, and data available on this site, and it is primarily a heavy metal contamination problem.

Several emergency removals have been initiated in and around this superfund site. Sediment removals in Torch Lake due to the discovery of heavy metal and PCB sludge in public swimming areas have also occurred. These areas along the beaches were previously assumed to be “clean.” Concentrations far above human direct contact criterion for heavy metals (lead in the range of 72,000 ppm for example) have been documented in areas that have been designated as swimming beaches. This same sludge contained significant concentrations of PCB, a contaminant known to be present in Torch Lake and also found in fish.

The aquatic problems and huge dead zones at the base of Torch Lake are clearly documented. The shore of the lake is available for swimming and wading. Multiple industrial processing sites surround the entire lake and the potential for sludge and industrial waste to be present is currently unknown due to limited assumptions and poor characterization in the late 1980’s and early 1990’s. More recent data, however, has found these earlier studies to be lacking.

The site problems stem from an inadequate characterization, a flawed site conceptual model, and poor sample collection for long term monitoring. The prior two mentioned above have also led to a poor data analyses and the inability to draw appropriate conclusions from data that has been collected. These are general statements to summarize the problems that can be highlighted from the data we currently have on the site. Heavy metals including mercury, PCBs

The sources are the extensive stamp sand deposits and the multitude of industrial stamp sand processing, chemical leaching, explosives manufacturing plants, and the smelting operations. These industrial facilities were not addressed in the ROD and the stamp sands were assumed by the USEPA to be homogeneous and essentially benign except for the ongoing high heavy metal concentrations going into the lake due to windblown and water driven erosion (thus the capping strategy). The areas sampled and the frequency and depth of the characterization sampling in and around the stamp sands were not sufficient for making the conclusion to cap these sands. They are now known to include heavy metal rich sludge, layers of industrial processing waste under the lake and adjacent to processing facilities. Ammonia plumes, nitrates, and heavy metal rich groundwater plumes are now known to exist that of course contribute to the metals concentrations in sediment under the lake.

Torch Lake was the site of copper milling and smelting facilities and operations for over 100 years. The lake was a repository of milling wastes and served as the waterway for transportation to support the mining industry. The first mill opened on Torch Lake in 1868. At the mills, copper was extracted by crushing or "stamping" the rock into smaller pieces, grinding the pieces, and driving them through gravimetric sorting in a liquid medium. The copper was sent to a smelter. The crushed rock particles, called "tailings," were discarded along with mill processing water, typically by pumping into the lakes. Mining output, milling activity, and tailing production peaked in the Keweenaw Peninsula in the early 1900s to 1920. All of the mills at Torch Lake were located on the west shore of the lake and many other mining mills and smelters were located throughout the peninsula. In about 1916, advances in technology allowed recovery of copper from tailings previously deposited in Torch Lake. Dredges were used to collect submerged tailings, which were then screened, re-crushed, and gravity separated. An ammonia leaching process involving cupric ammonium carbonate was used to recover copper and other metals from conglomerate tailings. During the 1920s, chemical reagents were used to further increase the efficiency of creosotes, wood creosote, pine oil, and xanthates. After reclamation activities were complete, chemically treated tailings were returned to the lakes. In the 1930s and 1940s, the Torch Lake mills operated mainly to recover tailings in Torch Lake. In the 1950s, copper mills were still active, but by the late 1960s, copper milling had diminished.

Over 5 million tons of native copper was produced from the Keweenaw Peninsula and more than half of this was processed along the shores of Torch Lake. Between 1868 and 1968, approximately 200 million tons of tailings were dumped into Torch Lake filling at least 20 percent of the lake's original volume. In June 1972, a discharge of 27,000 gallons of cupric ammonium carbonate leaching liquor occurred into the north end of Torch Lake from the storage vats at the Lake Linden Leaching Plant. The Michigan Water Resources Commission (MWRC) investigated the spill. The 1973 MWRC report discerned no deleterious effects associated with the spill, but did observe that discoloration of several acres of Lake Bottom indicated previous discharges. In the 1970s, environmental concern developed regarding the century-long deposition of tailings into Torch Lake. High concentrations of copper and other heavy metals in Torch Lake sediments, toxic discharges into the lakes, and fish abnormalities prompted many investigations into long-and short-term impacts attributed to mine waste disposal. The International Joint Commission Water Quality Board designated Torch Lake as a Great Lakes Area of Concern in 1983. Also in 1983, the Michigan Department of Public Health announced an advisory against the consumption of Torch Lake sauger and walleye. The Torch Lake site was proposed for inclusion on the National Priorities List (NPL) in October of 1984. The site was placed on the NPL in June 1986. The Torch Lake site is also on the Act 307 Michigan Sites of Environmental Contamination Priority List.

A Draft Remedial Action Plan ("RAP") for Torch Lake was developed by MDNR in October 1987 to address the contamination problems and to recommend the remedial action for Torch Lake. Revegetation of lakeshore tailings to minimize air-borne particulate matter was one of the recommended remedial actions in the RAP.

CSM summary: The remedy assumed cutting off the stamp sand erosion from wind and water into Torch Lake would reduce accumulation of heavy metals that caused the sediment toxicity. The reality is that this assumption was not correct and the characterization of the source areas was not sufficient to have drawn this conclusion.

We now know and acknowledge that this is the site of the world's richest copper deposits and mining, and extensive mining and industrial processing of tailings including chemical leaching of the tailings occurred at this site. Tailings and industrial process wastes are scattered all over Houghton County. Torch Lake was the disposal point for the ore and segregation of the tailings was the first process. This removed the solid pieces of copper for processing. The stamped sands and ore containing less rich deposits were segregated some washed into the lake and some put in waste piles. The percentage of copper in these wastes was still greater than deposits around the world and in the U.S. so it was economical to process it again. Copper rich sands deposited in the lake were dredged out (over the history of the site several times) and chemically processed to leach out the copper. Any heavy metals associated with this extremely rich copper deposit were of course released to the lake and sludge rich in metals, fatty acids, ammonia compounds were deposited like deltas along the shore of the lake.

Large smelting and ore processing facilities involving much waste and again, heavy metals other than copper, were also scattered around the county. These facilities also used the lake as their disposal mechanism and a lot of process wastes were sent to Torch Lake for disposal.

Heavy metal smelting plumes downwind of the smelters have never been investigated to date even in populated areas. The mercury and metals of concern from these smelters that can wash continuously into the watershed are not yet acknowledged.

There are of course sources that are richer and more toxic than the smelter plumes. The human health exposure and neighborhood soils and erosion of these heavy metals could still be significant, however currently unknown.

Groundwater is not acknowledged as a contaminant transport mechanism in the current ROD. It has however, been conclusively demonstrated to be a transport mechanism from these on-site industrial facilities to the lake. These sources need to be acknowledged, investigated, and very likely controlled to facilitate a shorter recovery time for this very large lake and watershed.

A.74.4 Remedial Objectives

The risks posed at the site are to human health through a variety of exposure routes including drinking water, direct contact, inhalation, and consumption of fish mostly due to heavy metal particulates in the air and heavy metals deposited in the sediment of the lake (PCB however are also found in the fish). The beneficial use of the resources has been extremely impaired due to heavy metal and other toxic organic contaminant sludge deposited in the lake.

RAO(s)/Project objectives: The objective was essentially to stop the ongoing loss of stamp sands from wind and water erosion to the lake as well as to reduce the inhalation of heavy metal particulates.

A.74.5 Remedial Approach

Final selected remedy: The soils and vegetated caps are currently minimally effective. The stamp sands are toxic to soil microbes and algae due to the high copper content so a fertile, well microbially populated soil profile will never develop. The soil cover was likely too thin and too lean in nutrient rich organic materials to sustain a culture that would support vegetative growth. These conditions continue to be documented and investigated. For this remedy to work long term, it is necessary to enhance the fertility of the topsoil in order to sustain an effective cover. Groundwater leaching through this material is not acknowledged in this remedy as an input to Torch Lake. These stamp sands are a mixture of industrial sludge rich in all of the waste toxic heavy metals as well as the original leaching fatty acids and ammonia and nitrate compounds that leached the copper from the stamp sands on the successive industrial processing. These types of contaminant transport dynamics were also not acknowledged in the decision documents. They have been documented and are known to be a problem.

These operable units are the first and third of three operable units for the site. The selected remedial action for these operable units addresses the tailings and slag piles/beach at the site. Operable Unit II, which is not a part of this ROD, addresses the groundwater, surface water, and sediments. The major components of the selected remedy include:

- Deed restrictions to control the use of tailing piles so that tailings will not be left in a condition which is contrary to the intent of this ROD
- Removal of debris such as wood, empty drums, and other garbage in the tailing piles for off-site disposal in order to effectively implement the soil cover with vegetation
- Soil cover with vegetation

Why the remedy was selected: Stabilization of the stamp sands with a vegetative cap should slow down the constant deposition of heavy metal contaminated sands into Torch Lake both from wind erosion and sedimentation due to run off and wave action erosion. Inhalation of the heavy metal dust was also determined to be of risk to the residents.

Primary lines of evidence used to investigate MNR: MNR is what is expected to happen in the lake as a result of cutting off the continued influx of heavy metals from the stamp sand deposits. The contaminant transport and geochemistry of the highly contaminated sediments were never investigated and the impact of groundwater and interaction of groundwater with these waste piles and chemical processing waste full of residual leaching chemicals entrained in sludge in the lake as well as on the shore were never acknowledged or considered by USEPA. Heavy metals are increasing in concentration at the base of the lake at alarming rates, and this was of course never anticipated by USEPA. Studies conducted on the sediment by Michigan Technological University have concluded that the MNA recovery time could be 850 years or more to reach concentrations where aquatic life could return to the bottom of the lake.

Expected recovery time: The time as mentioned in the MNR summary above is at least 850 years or more. This was not anticipated by the original ROD due to the poor characterization, not acknowledging the geochemical relationship of sediments or understanding how contaminated they were, nor defining the methods of contaminant transport that include extensive groundwater plumes that are still active from these extensive ongoing industrial sources as input of metals into the lake. No cost information is available.

A.74.6 Monitoring

The lake sediments will be monitored in selected areas to track the progress toward reduction in heavy metals. The monitoring thus far has conclusively demonstrated the most contaminated materials are in the upper column of the sediment profile and decreasing with depth. This contaminant profile is of course contrary to the disposal and stamp sand processing history of the site which would have left the most contaminated material at depth and the most recent processed materials with less metal content on the surface of the sediment profile. The stamp sands vegetative caps are also to be inspected annually and repairs to the cap made if necessary.

Monitoring elements: The elements include cap inspection, institutional controls for construction and disturbance of the cap as well as the ongoing lake sediment and biological monitoring that is needed to track the anticipated recovery of the lake.

RAOs/project objectives achieved? Not yet relevant. The construction of the caps is complete; however, it is too soon to determine their effectiveness. The input from stamp sands eroding and blowing into the lake has been reduced. The monitoring of the sediment confirmed that the sediments that predate the capping of the stamp sands show increasing concentrations that are not in any way related to the decrease in sedimentation due to the caps. There is a beneficial effect for the caps; however, it is difficult to assess how much at this point in time that this effort has reduced the rate of increase in heavy metal concentrations near the surface water interface in Torch Lake.

A.75 Town Branch, KY

A.75.1 Summary

Environment:	Freshwater
Scale:	
Contaminants of Concern:	PCBs
Final Remedy:	Dams with bypass pumping of creek flow to dry out target areas. Contaminated sediment was sent off site to Emelle, Alabama (TSCA waste <50 ppm), non-TSCA waste sent to local solid waste landfill.

A.75.2 Site Description

Year: 2000

Target Volume: 290,000 yd^3

Actual Volume Removed: 239,000 yd^3

A.75.3 Remedial Objectives

0.1 ppm PCBs or to extent practicable

Contaminated sediment area: 3.5 mile sector

A.75.4 Monitoring

No suspension measures were needed because dry excavation was used.

Performance/ Yes, goals were initially reached until it was realized a few years later that PCB levels were back up due to a NAPL source. A NAPL recovery system was put in to stop recontamination.

A.75.5 References

Doody, J. Paul and A. D. Weeks. Sediment Removal and Restoration of Town Branch Creek in Russellville, Kentucky. American Society of Civil Engineers, pp. 1-14. doi: http://ascelibrary.org/doi/abs/10.1061/40680%282003%2982. http://cedb.asce.org/cgi/WWWdisplay.cgi?0304704.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.smwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.76 Twelve-Mile Creek/Lake Hartwell, Pickens County, SC

Sangamo Weston, Inc., Twelve-Mile Creek, Lake Hartwell, Operable Unit 2

A.76.1 Contacts

Craig Zeller
USEPA
zeller.craig@epa.gov

A.76.2 Summary

Environment:	Freshwater lake
Scale:	7 mile stretch of Twelve-Mile Creek and 730 acres of the Twelve-Mile Creek arm of Lake Hartwell
Contaminants of Concern:	PCBs
Source Control Achieved Prior to Remedy Selection?	Yes
Final Remedy:	MNR for Twelve-Mile Creek arm of Lake Hartwell
Expected Recovery Time:	12 years
MNR viewed as a success?	Yes

A.76.3 Site Description

Primary Pathway: Human health via fish consumption, benthic

Primary source(s): The primary source of the contaminants is from a company named Sangamo Weston who manufactured electrolytic mica and power factor capacitors from 1955 to 1978. PCB use at this plant was terminated in 1977.

Location: The Sangamo Weston, Inc. /Twelve-Mile Creek/Lake Hartwell PCB Contamination Site is located in Pickens County, South Carolina. It is made up of the Sangamo property, portions of Twelve-Mile Creek, and the Twelve-Mile arm of Lake Hartwell.

The affected areas of sediment are a 7-mile stretch of Twelve-Mile Creek and 56,000-acre Lake Hartwell (artificial reservoir created by the construction of Hartwell Dam across the Savannah River) (USEPA 2004b). Twelve-Mile Creek is the primary tributary into the headwaters of the lake and contains three masonry impoundments (private dams) along its length. Sediment in both Twelve-Mile Creek and Hartwell Lake contains PCBs that originated from a Sangamo Weston capacitor plant that discharged PCB-containing wastewater into Town Creek, a tributary to Twelve-Mile Creek. From 1955 to 1977, a yearly average amount of PCBs used at the Sangamo Plant in Pickens County, SC ranged from 700,000 to 2,000,000 pounds. It is estimated that 3%, approximately 400,000 pounds, of the quantity of PCBs used at the plant ended up being discharged into Town Creek.

Sediment PCB concentrations in the lower 7-mile stretch of Twelve-Mile Creek, interchangeably known as the Twelve-Mile Creek Arm and Seneca Creek Arm, and a depositional area, were originally measured in the 1–3 ppm range at the surface and higher in deeper sediments. Portions of the Twelve-Mile Creek Arm were found to contain up to 61 ppm PCBs. In 1991/92, maximum

PCB concentrations measured in sediment core samples from the upper section of Lake Hartwell (where Twelve-Mile Creek enters) exhibited concentrations of 5–11 ppm; PCB concentrations in sediment in the lower part of the lake were typically < 1 ppm.

A.76.4 Remedial Objectives

In June 1994, a ROD was issued for the site that specified MNR supplemented by institutional controls as the selected remedy. The selected target cleanup standard for sediment was 1 ppm PCBs based on technical feasibility; the affected area covers approximately 730 acres with a total estimated volume of 4.7 million yd^3 of PCB-contaminated sediment. For fish, the FDA action level of 2 ppm PCBs was selected, also based on technical feasibility. A carcinogenic risk-based approach was evaluated by determining the concentration levels in largemouth bass that would result in acceptable risk to anglers through ingestion of fish. Using USEPA risk assessment methods, a fish tissue concentration of 0.036 ppm was associated with a 10^{-4} risk. The risk-based fish cleanup goal of 0.036 ppm was determined to be technically impracticable. Natural recovery of largemouth bass within Hartwell Lake to below the FDA action level of 2 ppm PCBs was predicted by modeling to occur within 12 years (by 2004).

A.76.5 Remedial Approaches

Sediment cores were collected in Lake Hartwell and provided data used to determine the vertical profile of PCBs in the sediment column. These data indicated that higher PCBs were being buried beneath sediment with lower PCB concentrations. Sediment Transport Modeling predicted net sediment accumulation in the lake to be 5 to 15 cm/yr. Two long-term fate and bioaccumulation models were constructed to enable predictions of PCB concentrations in sediment and fish in Lake Hartwell over time under various potential remedial approaches. A water-quality model was developed to determine the fate of PCBs in the system over time, and results of this model indicated that PCB concentrations in the water column and sediment of Lake Hartwell would generally decrease over time, even in the absence of any intrusive remediation. The primary mechanisms for PCB reductions over time were boundary transport and burial. A bioaccumulation model was also constructed to complement the water-quality model and to estimate PCB concentrations in fish tissue over time. The results from this model indicated that largemouth bass PCB levels would decrease to < 2 ppm (in fish weighing greater than 3.4 kg) in 12 years under an MNR scenario. Results from these models were used in establishing the ROD for the site.

A.76.6 Monitoring

Annual biota and sediment monitoring has been implemented in the spring of each year since 1994. This effort has included (1) surface sediment sampling at 21 locations in Twelve-Mile Creek and Lake Hartwell; (2) fish tissue analyses at six stations in Lake Hartwell for largemouth bass, catfish, and hybrid bass; (3) fish tissue analyses on forage fish species at three locations in Lake Hartwell; and (4) 28-day caged corbicula analyses at seven stations in Twelve-Mile Creek. The 2004 USEPA Five-Year Review reported, sediment data indicate that surficial sediment PCB concentrations in Twelve-Mile Creek have decreased steadily since 1990 due to ongoing physical processes such as burial, mixing/dispersion, and PCB dechlorination. However, the same USEPA Five-Year Review concluded that, although sediment concentrations continue to measurably decrease, PCB concentrations in largemouth bass, channel catfish, and hybrid bass have not responded as measurably to the decreased surface sediment trends.

A 2006 technical agreement between the Natural Resource Trustees and the principal responsible party, Schlumberger Technology Corporation, requires, among other things, the removal of two of three dams (Woodside 1 and 2) on the Twelve-Mile Creek Arm of Lake Hartwell. An Explanation of Significant Differences was issued in 2009 to support this aspect of the project as it is expected to enhance the ongoing natural transport of clean sediment downstream to speed burial of the PCB-contaminated sediment in Lake Hartwell. The removal of these two dams was completed as of 2011.

A.77 St. Louis, MI

A.77.1 Contacts

Regulatory Contact: Michigan DEQ & USEPA
Site Contacts: Scott Cornelius, Michigan DEQ; Tom Alcamo, USEPA Region 5

A.77.2 Summary

Environment:	River
Scale:	Full
Contaminants of Concern:	PBB, DDT, PCBSa, pesticides, brominated compounds, rare earth/radioactive contaminants, variety of unknown designer chemicals (The list is quite large, this is a short summary.)
Source Control Achieved Prior to Remedy Selection?	Original remedy: Failed slurry wall and cap. DDT contaminated sediment removal 2007.
Final Remedy:	Proposed plan not yet completed, however, currently anticipated: On-site treatment, capping, groundwater pump & treat, slurry wall containment, NAPL/DNAPL removal/treatment, city water supply replacement, 97 million sediment removal (already completed). Downstream Pine River cleanup under evaluation and monitoring. (much more going on)
Expected Recovery Time:	To be determined
MNR viewed as a success?	Yes. Monitoring of residual contamination and assessment of sediment rates are ongoing.

A.77.3 Site Description

The Velsicol Chemical Superfund Site is located in the center of the City of St. Louis Michigan and the 52 acres of plant site is on the shore of a large impoundment on the Pine River that currently produces hydroelectric power for the city. The city water supply is in the regional aquifer system and the water supply wells are located adjacent to the plant site and have been determined to be in hydraulic connection with groundwater recharge from the plant site. The site extends also to the downstream contamination in the Pine River that is below the impoundment. High concentrations of DDT that are accumulating in fish and aquatic organisms need to be addressed due to the high concentrations found in the sediment for a significant distance downstream of the plant site.

The USEPA Record of Decision (ROD) for this operable unit for the Velsicol Superfund Site led to a sediment removal in the Pine River adjacent to the plant site. The Pine River runs through the City of St. Louis and there is an impoundment that forms the boundary for the limits of the excavation. The ROD found that a removal of all the DDT contaminated sediment behind the dam was necessary. Sheet piling was used to control the river while dewatering and “dry” excavation of the sediment was implemented. This was done in successive seasons and the flow of the channel successively managed while sediments were removed from the channel behind the impoundment.

The excavation process uncovered extensive non-aqueous phase liquids (NAPL) moving through the fractured till under the river prior to dewatering. This same NAPL is dense and also mobile. It is now known to have moved to a depth of 100 ft below the plant site and has been found to be present and recoverable in the permeable sand regional aquifer that supplies the cities drinking water.

The design and RI eventually found many more NAPL locations that currently, or at some point in the future have the potential to move off the plant site into the Pine River. This condition therefore has a great potential to recontaminate the river with extremely toxic DDT, other pesticides, and brominated compounds.

The sediments were successfully removed by excavation. The concentrations of bioaccumulative contaminants, DDT, and other pesticides were determined necessary to remove, other treatment options were not protective.

A NAPL collection system is currently installed under the river with a designed containment cap to separate this NAPL from further contact with the river. The NAPL is mobile, contains percentage concentrations of DDT and many other contaminants that will cause damage to the Pine River. This NAPL threatens to recontaminate the section of river already cleaned up.

The cost of the cleanup was approximately 97 million dollars. The monitoring and evaluation of the collection system is ongoing and the evaluation of the success of the excavation and long term monitoring is also currently in effect. The final design and excavation sampling results are also available for evaluation of the success of the removal process.

The primary source of contamination at this site is the 52 acres of the Velsicol Chemical Plant site located adjacent to the Pine River. Years of operational losses, dumping, and spills led to widespread DDT contaminant concentrations and a whole host of hazardous chemicals lost to the Pine River. Pathways for exposure are air born deposition in the community and extensive NAPL and DNAPL contamination that is in groundwater and hydraulic contact with the bed of the Pine River. Recoverable DNAPL is present at 100 ft below the plant site and is in contact with the regional aquifer that supplies the City of St. Louis. This same NAPL is under the river and contains extremely high levels of DDT dissolved in chlorobenzene and other chlorinated solvents.

There is a long and highly complex site history that involves State of Michigan and Velsicol Chemical Company legal agreements, USEPA involvement, bankruptcy negotiations, a failed remedy determination, and the potential for this site to be the most costly fund lead site to date for the USEPA to finance. This history is brief and cannot do justice to the complicated site history due to the number of factors involved.

The Velsicol Chemical Plant site is located adjacent to an impoundment on the Pine River in City of St. Louis, Michigan. This chemical plant site produced a variety of toxic chemicals and was a major producer of DDT and brominated fire retardant chemicals such as PBB that was introduced into feedstock for chickens and cattle. It was then introduced into Michigan's food supply. Velsicol also produced a fungicide that causes male sterility.

The plant site had been in operation since the 1930's and dumping of waste into the Pine River both legal and illegal occurred as long as the plant was in operation. The site was dealt with in the 1970's by razing the plant site, hauling highly contaminated soils back to the plant site from a local illegal dump site, installation of a slurry wall between the plant site and the Pine River and a cap to prevent continued recharge of the waste from rainfall. Water levels inside the slurry wall were to be monitored and if increasing above a certain level were to be pumped out. The conditions required were not properly dealt with by the Velsicol Chemical Company; they went bankrupt and left the State of Michigan and the USEPA with a failed remedy that now appears to be one of the most costly fund lead cleanups by the USEPA to date. The USEPA Record of Decision (ROD) for this operable unit for the Velsicol Superfund site led to a 97 million dollar sediment removal in the Pine River impoundment behind the dam and adjacent to the plant site.

The Pine River runs through the City of St. Louis and the impoundment forms the boundary for the limits of the excavation. The ROD found that a removal of all the DDT contaminated sediment behind the dam was necessary. Sheet piling was used to control the river while dewatering and "dry" excavation of the sediment was implemented. This was done in successive seasons and the flow of the channel successively managed while sediments were removed from the channel behind the impoundment.

During the excavation, extensive NAPL and DNAPL problems were encountered. A seam of sand in the till unit produced over 3,000 gallons of DDT contaminated chlorobenzene and other solvents. The DDT was in percentage concentrations and this sand unit and NAPL was in hydraulic contact with groundwater and the Pine River. Many discreet NAPL/DNAPL were identified on the site during the remedial investigation. Some are known to underlie the river and others are suspected to be in hydraulic contact with groundwater that either vents to the river or finds a path to recharge the regional aquifer system. Hydraulic heads in the groundwater system are both horizontal to the Pine River and downward into the regional aquifer system.

CSM summary: The site was dealt with in the 1970's by razing the plant site, hauling highly contaminated soils back to the plant site from a local illegal dump site, installation of a slurry wall between the plant site and the Pine River and a cap to prevent continued recharge of the waste from rainfall. Water levels inside the slurry wall were to be monitored and if increasing above a certain level were to be pumped out. Velsicol Chemical did not maintain or operate the remedy properly and the original remedy failed. The slurry wall was assumed to be keyed into a low permeability clay, when in fact it was a fractured till with sand seams and silt.

This till has been found to be chemically weathered by the solvents and did not serve as a low permeable barrier to the transport of chemicals both vertically and laterally in the groundwater system. NAPL and DNAPL have independently moved through the till fractures and sand seams both horizontally off the plant site and under the Pine River as well as downward to at least 99 ft below the plant site and directly adjacent to the Pine River. Three thousand gallons of NAPL were removed during the excavation of the sediment on top of the till when the backhoe penetrated a sand lens. This same unit continues to produce NAPL from a designed collection trench and piping that now resides below the Pine River with a clay cap over the area where the NAPL originally expressed itself. This NAPL contains percentage concentrations of DDT and, if not managed properly, has the potential to re contaminate the sediments that cost 97 million dollars to remove.

The plant site dumped chemical waste both legally and illegally into the Pine River impoundment since the 1930's. The 52 acres of plant site had many chemical processing and production facilities that were also subject to spilling, dumping, and pipeline losses as well. Tank farms for raw product as well as final product storage were subject to continued leaks over the years of plant operation. There are several permeable units that underlie the plant site that discharge contaminated groundwater and NAPL and DNAPL DDT and other solvent dissolved phase contaminants directly to the Pine River along with recently discovered old piping that was never dealt with appropriately when the earlier slurry wall was constructed.

These conditions led to the DDT contamination behind the impoundment as well as downstream in the Pine River. Contamination in the impoundment was removed by excavation after dewatering and sheet piling to manage the Pine River flow through the area. The downstream contamination still needs to be addressed and is currently being monitored and evaluated.

The groundwater and contaminants from the site move both laterally into the Pine River and downward into the regional groundwater aquifer system that supplies the drinking water for the City of St. Louis. The hydraulic head is both down and lateral into the Pine River thus complicating the long-term remedy options for protecting the Pine River from becoming contaminated again.

A.77.4 Remedial Objectives

The risks posed at the site are to human health through a variety of exposure routes including drinking water, direct contact, inhalation, and consumption of fish from the Pine River currently contaminated with DDT. Both terrestrial and aquatic life have been found to be impacted with a variety of site specific chemicals that continue to seep into the ecosystem from the plant site.

RAO(s)/Project objectives: This section identifies the site-specific RAOs. These RAOs pertain to "general site cleanup" or are intended to fulfill potential federal and state ARARs and "to be considered "criteria (TBCs). The RAOs proposed for this site, where DDT and its breakdown products are the primary constituents of concern, are as follows:

- Reduce DDT concentrations in fish and sediments in the St. Louis.
- Impoundment to levels that would not present an unacceptable human- health or ecological risk and would allow eventual elimination of existing fish consumption advisories.
- Prevent direct human contact with contaminated sediments.
- Prevent significant down river migration of contaminated sediments.
- Achieve compliance consistent with federal and state ARARs for the Site.
- Comply with risk-based objectives defined by the risk assessment.

The contaminant removal behind the impoundment found that almost all the sediments in the area designated for removal needed to be excavated. The sediment was removed down to the till layer that formed the base of the Pine River, so regardless of the RAO(S), the impoundment was excavated down to the till.

A.77.5 Remedial Approach

Final selected remedy: The operable unit for excavation of sediments in the impoundment was based upon high levels of DDT contamination in the sediment causing risk for aquatic, terrestrial, and human food chains. The containment remedy for the 52 acre plant site has yet to be determined; however, the Feasibility Study focuses on a variety of options that include capping, sheet piling, groundwater pump and treat, NAPL/DNAPL removal and collection, replacement of the City of St. Louis water supply, and on-site treatment of contaminated soils and liquids to reduce the concentrations prior to capping. The glacial till unit below the plant site is permeable therefore resulting in no reliable low permeability base to the final containment remedy. Reduction and destruction of high and mobile contaminant concentrations therefore was deemed necessary.

Removal of the sediments in the impoundment through sheet piling and dewatering of the area to excavate under relatively dry conditions. The main plant site includes capping, sheet piling, groundwater pump and treat, NAPL/DNAPL removal and collection, replacement of the City of St. Louis water supply, and on-site treatment of contaminated soils and liquids to reduce the concentrations prior to capping.

Primary lines of evidence used to investigate MNR: MNR is not currently part of this remedy. The downgradient of the impoundment contamination of the Pine River is still being evaluated and data collection is ongoing.

A.77.6 Monitoring

Not yet applicable to this site.

Expected recovery time: Not yet applicable to this site.

Projected monitoring costs: Not yet applicable to this site.

RAOs/project objectives achieved? Not yet applicable to this site.

A.78 Vineland, NJ

Vineland Chemical

A.78.1 Contacts

Regulatory Contacts:

US Environmental Protection Agency, Region 2:
Betsy Donovan 212-637-4369
Nica Klaber 212-637-4309
Ron Naman 212-637-4375

A.78.2 Summary

Environment:	Marsh/wetland/floodplain
Scale:	Full
Contaminants of Concern:	Arsenic
Source Control Achieved Prior to Remedy Selection?	Yes (Contaminated groundwater under control)-unsure if contaminated soil and sediment under control
Final Remedy:	Excavation and MNR
MNR viewed as a success?	Yes

A.78.3 Site Description

Primary source(s): Improper storage of arsenic salts on the plant property led to soil and groundwater contamination. Prior to 1977, the company stored arsenic salts in open piles and in abandoned chicken coops. Arsenic contamination, attributable to the Vineland Chemical Company, has been detected in the soils and groundwater at the plant site and has been detected in surface waters and sediments as far as 36 miles downstream from the plant.

Location: The 54-acre Vineland Chemical Company site is located in Vineland, Cumberland County, New Jersey in a mixed industrial/residential area. The site is surrounded by residential properties. Currently the majority of the site is covered with vegetation with the exception of the parking lots and a paved manufacturing area.

The Vineland Chemical Company manufactured arsenic based herbicides from 1950 to 1994. The plant site included a number of manufacturing and storage buildings, a laboratory, several lagoons, and former chicken coops. As a result of waste storage practices, arsenic contaminated the adjacent wetland, site soil, groundwater, and the nearby Blackwater Branch, Maurice River, and downstream Union Lake.

By 1982, the Vineland Chemical Company, in response to State actions, instituted some cleanup actions and modified the production process. These modifications included: installing a non-contact cooling water system, lining two of the lagoons, installing a stormwater runoff collection system, and disposing of piles of waste salts. Also, in 1982, the company, under a State Administrative Order, began operating a wastewater treatment system to remove arsenic. The system received contaminated process water and groundwater from two lined surface impoundments and discharged treated water to percolation lagoons. The treatment was only able to process 35,000 gallons per day while an estimated 150,000 gallons per day left the site. Additionally, the system was unable to reduce arsenic concentrations to acceptable levels. Approximately 57,000 people depend on the groundwater system in the area for drinking water through private or municipal wells.

A.78.4 Remedial Objectives

Remediation risks at this site include dredging activities, which could disturb riverine and wetland areas, causing potential environmental impacts.

The Vineland Chemical Company site received $20 million in American Recovery and Reinvestment Act funding for the river areas remedial construction. A diversion channel will be constructed to divert the Blackwater Branch while arsenic contaminated sediments are excavated from the stream channel and buffering wetlands areas. The stream channel and wetlands will be backfilled and restored with indigenous vegetation. The goal of this remedy is to eliminate secondary source material, which adds arsenic contaminant load to downstream river environs and Union Lake.

After stopping the flow of arsenic contaminated groundwater from the site, a three year period for natural river flushing will be implemented. This will allow the submerged, arsenic contaminated sediments in the Maurice River to be flushed clean through natural processes. If, after this period, the submerged sediments are no longer contaminated with arsenic above the action level, no remediation will be performed in the river.

A.78.5 Remedial Approach

Final selected remedy: Excavation

Site cleanup is being addressed in two stages. The cleanup has been separated into immediate actions and four long-term remedial phases focusing on source control, contaminant migration management, and the cleanup of marsh, river, and lake sediments.

- Operable Unit One (Plant Site Source Control): Alternative SC-5: In Situ Flushing
- Operable Unit Two (Plant Site Management of Migration): Alternative MOM-4A: Site pumping/treatment/reinjection/discharge to the Maurice River

- Operable Unit Three (River Areas Sediments): Alternative 3C: Dredging/excavation/extraction/floodplain deposition of exposed sediments/plant site deposition of river sediments/off-site hazardous sludge disposal
- Operable Unit Four (Union Lake Sediments): Alternative 3: Removal/extraction/lake deposition of sediments/off-site hazardous sludge disposal

The USEPA has demolished and removed contaminated buildings on the plant site property and removed and disposed of hazardous chemicals stored/abandoned on the site. USEPA also constructed a groundwater extraction and treatment system, which has been operating since 2000, to control the off-site migration of groundwater contamination. Through use of a soil washing system, USEPA has processed over 400,000 tons of arsenic-contaminated soil/sediments and returned 95 percent of the material to the site as clean backfill. Finally, USEPA has completed cleanup of the first three sections of the Blackwater Branch through a combination of soil washing and off-site disposal.

The selected remedies for operable units 1 to 3 are protective of human health and the environment, comply with federal and state requirements that are legally applicable or relevant and appropriate to these remedial actions, and are cost effective. They use permanent solutions and alternative treatment technologies to the maximum extent practicable and satisfy the statutory preference for remedies that employ treatment that reduces toxicity, mobility, or volume as a principal element.

The selected remedy for OU 4 is an interim remedy that protects human health and the environment and provides for further monitoring and study to determine the scope and nature of any additional action which may be necessary. The supplemental study will address the dynamics of sediment transport to, within, and from Union Lake and will deal with the effect of arsenic on biota. The interim remedy will meet the statutory preference, with the exception of permanence. It will result in hazardous substances remaining in Union Lake above health-based levels and will be subject to a five year review.

A.78.6 Monitoring

Monitoring elements: The USEPA is performing environmental studies to evaluate the need to clean up the river and lake sediments. These long-term studies will use data collected before and during the cleanup activities involving soil and groundwater. The groundwater treatment plant is anticipated to operate for 15 years.

RAOs/project objectives achieved?

- OU 1: On-site soils were processed in a soil washing facility and meet criteria set out in the ROD.
- OU 2: Groundwater extraction and treatment is ongoing.
- OU 3: The phased sediment excavation along the Blackwater Branch is ongoing. USEPA completed the cleanup of arsenic contaminated sediment associated with the first phase of

the Blackwater Branch in December 2007. By October 2009, much of the contaminated sediment associated with phase 2 had been excavated and disposed off site.

A.78.7 References

USEPA Superfund Site Information. http://cfpub-.epa.gov/supercpad/SiteProfiles/index.cfm?fuseaction=second.contams&id=0200209.

A.79 Waukegan Harbor, IL

A.79.1 Summary

Environment:	Freshwater
Scale:	Full
Contaminants of Concern:	PCBs: upper harbor concentrations average between 50 and 500 ppm. Hot spot (Slip 3): greater than 500 ppm with max 10,000 ppm
Final Remedy:	Hydraulic cutterhead dredge. Slip 3 sediment was treated by thermal desorption. Upper harbor contaminated sediment was pumped directly into Slip 3 and the remaining water was pumped out. The landfill was capped and covered with grass.

A.79.2 Site Description

Outboard Marine

Year: 1989

Water Depth: 14–25 ft

The freshwater harbor sediments consisted of 1 to 7 ft of very soft organic silt (muck) overlying typically 4 ft of medium dense, fine to coarse sand. The sand is generally uncontaminated.

Target Volume:

Slip 3: 10,900 yd^3

Upper harbor: 35,700 yd^3

Actual Volume Removed:

Slip 3: 6,300 yd^3

Upper harbor: 32,000 yd^3

A.79.3 Remedial Objectives

Modeling concluded that residual PCBs between 10 and 100 ppm left would result in negligible PCB influx to Lake Michigan, near zero. Based on this, USEPA set a 50 ppm cleanup level. USEPA calculated 96% PCB mass would be removed from the Upper Harbor if 50 ppm was met.

The contaminated sediment area was 10 acres of the 37 acre harbor.

A.79.4 Remedial Approach

Hydraulic cutter head dredge

Slip 3 (a functioning dock/marina at one time) was dug out and lined to be used as an on-site landfill; upper harbor was pumped directly into landfill.

A.79.5 Monitoring

Resuspension:

The entire harbor is bordered by 20-25 ft sheet pilings. Silt curtains were anchored to the bottom at the lower part of the Upper Harbor to contain suspended contaminants. Silt curtains failed due to wind and wind driven currents.

Performance:

After the completion of the Upper Harbor dredging and water treatment, the harbor water was sprayed with Nacolyte, a potable coagulant, to aid the settling of suspended particles in the harbor. The silt curtains were removed 48 hours after the application of the coagulant. Further dredging is to be done at this site in late 2012. A goal of a SWAC of 0.2 ppm PCB with a 6 inch clean sand cap will be obtained.

Residuals:

98% of PCBs were removed from the harbor.

A.79.6 References

USEPA Region 5 Cleanup Outboard Marine Corporation as updated Sep 2012. http://www.epa.gov/region05/cleanup/outboardmarine/index.htm.

USEPA Region 5 Superfund Outboard Marine Corp. EPA ID ILD000802827 as updated Oct 2012. http://www.epa.gov/R5Super/npl/illinois/ILD000802827.html.

USEPA Superfund Record of Decision: Outboard Marine Corp. EPA ID: ILD000802827. May 1984. http://www.epa.gov/superfund/sites/rods/fulltext/r0584007.pdf.

USEPA Superfund Record of Decision Amendment: Outboard Marine Corp. EPA ID: ILD000802827. Mar 1989. http://www.epa.gov/superfund/sites/rods/fulltext/a0589096.pdf.

USEPA. Second Five-Year Review Report for Outboard Marine Corporation Superfund Site. Sep 2002. http://www.epa.gov/superfund/sites/fiveyear/f02-05023.pdf.

USEPA Fourth Five-Year Review Report Outboard Marine Corporation Superfund Site. June 2012. http://www.epa.gov/region5/superfund/fiveyear/reviews_pdf/illinois/outboard_marine_corp_410945.pdf.

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.smwg.org/MCSS_Database/MCSS_Database_Docs.html.

A.80 Grand Calumet River (West Branch), Hammond, IN (Reaches 3, 4-5)

A.80.1 Contacts

Regulatory Agencies: USEPA Great Lakes National Program Office (GLNPO), U.S. Fish and Wildlife Service (USFWS), Indiana Department of Environmental Management (IDEM), Indiana Department of Natural Resources (IDNR), Hammond Sanitary District (HSD)

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A.80.2 Summary

Environment:	Inland river, freshwater, Great Lakes area
Scale:	Full
Contaminants of Concern:	PAHs, PAHs, PCBs, heavy metals, pesticides
Source Control Achieved Prior to Remedy Selection?	Yes / Site Characterization, Remedial Options Plan, Removal Action completed prior to placement of cap (Reaches 3, 4-5)
Final Remedy:	Dredging, Granular AC Cap, cover cap (Reaches 3, 4-5)
Expected Recovery Time:	3-5 years
Viewed as a success?	Yes /in-progress

A.80.3 Site Description

Primary source(s): Past direct discharges and releases from heavily industrialized urban inland waterway. About 90 percent of the river flow starts as municipal and industrial discharges, cooling and process water, and stormwater overflows.

The Grand Calumet River originates in the east end of Gary, Indiana and flows 13 miles through the cities of Gary, East Chicago, and Hammond, Indiana. The project focuses on a one-mile section of the West Branch of the Grand Calumet River. The WBGCR is a shallow, meandering creek approximately 50 ft wide and 1-2 ft deep during most of the year. The remaining surface area within the 150-wide channel had been overgrown with invasive species including the common reed. During heavy rains, water depth rises to several feet, covering the vegetation from bank to bank. Within the center of the WBGCR the soft sediment is about 10 ft deep.

The project is located in one of the most heavily industrialized areas in the United States. Past and present industrial operations in the area include steel mills, foundries, chemical plants, and oil refineries. Permitted discharges from industrial operations, municipal wastewater treatment plants, and other sources contribute substantial quantities of wastewater to the river system. Nonpoint sources of contaminants to the system include urban and industrial runoff, combined sewer overflows, leachate or overflow from a number of waste fills or ponds, and spills in and around industrial operations.

A.80.4 Remedial Objectives

Site characterization, source control, site remediation, and site restoration of a one-mile section of WBGCR, including: removal of 142,000 yd^3 of contaminated sediment (2-3 ft deep), followed by placement of cap over the dredged area, followed by habitat restoration of some of the most diverse native plant and animal communities in the Great Lakes Basin. The site remediation program is being coordinated with sewer improvements being made by the Hammond Sanitary District that include some sediment cleanup along this stretch of the river. Future plans include sediment remediation of Reaches 1-2 and 6-7, as well as the adjacent Roxanna Marsh.

Site-specific numerical Preliminary Remediation Goals (PRGs) for selected COCs and COC mixtures were developed largely using matching sediment chemistry and sediment toxicity data from the WBGCR. The PRGs were derived from site-specific concentration-response models designed to provide a basis for classifying sediment samples as toxic or not toxic based on whole sediment chemistry alone. Although PRGs were derived for eight trace metals, 12 individual PAHs and PAH classes, total PCBs, and various COC mixtures, no attempt was made to identify the substance or substances that were causing the observed toxicity in the WBGCR. The numerical PRGs for sediment-associated COCs also needed to address risks to aquatic-dependent wildlife associated with the bioaccumulation of certain COCs in the tissues of aquatic organisms (prey species). However, rather than developing wildlife-based PRGs, the level of protection offered to avian and mammalian species by the benthic PRGs was evaluated as a first step in the process, with GIS-based spatial analysis tools used to estimate average concentrations of key bioaccumulative COCs (for example, mercury and total PCBs) following implementation of the preferred remedial alternative. Simple bioaccumulation and food web models were then used to estimate post-remediation potential exposure and risks to aquatic-dependent wildlife.

Concerns for this case study include both ecological and human health risks associated with PCBs, PAHs, heavy metals, and pesticides. Based on an analysis of multiple lines of evidence, concentrations of a number of constituents in WBGCR sediments were sufficient to impact bed sediments and associated biological resources, including: trace metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc); PAHs (13 individual PAHs and total PAHs); PCBs (total PCBs); pesticides (chlordane, DDTs, heptachlor, and lindane); phenol; and unionized ammonia.

- The sediment cleanup action objectives are focused on addressing concerns relative to the bioaccumulation of COC in the tissues of benthic invertebrates, fish, and aquatic-dependent wildlife. The following RAOs were established:
- Reduce the concentrations of COCs in fish tissues to levels that are not associated with adverse effects on survival, growth, reproduction, or the incidence of lesions or tumors.
- Reduce the concentrations of COCs in the tissues of prey species to levels that do not pose unacceptable risks to insectivorous birds, sediment-probing birds, carnivorous-wading birds, piscivorous birds, or omnivorous mammals.
- Reduce the concentrations of COCs in fish to levels that do not pose unacceptable risks to human health. Surface water quality was addressed separately by IDEM through the development of TMDLs and the NPDES permitting process.

A.80.5 Remedial Approach

Final selected remedy: Mechanical dredging, granular AC cap, cover cap, and habitat restoration of a one-mile area of WBGCR. Remedial construction activities have been completed to date for Reach 3 (fall 2010) and Reach 4-5 (Fall 2011). Remedial Options Plan completed in 2006.

The remedial construction for Reaches 3 and 4-5 included: sheet pile coffer dam, semi-permanent weir, temporary steel sheet pile diversion barrier and intermediate barriers, dewatering system, temporary water treatment system, excavation to 4 ft below existing elevation, in situ sediment dewatering using drying agent, staging/off-site sediment disposal, installation of reactive core mats (RCMs) designed to capture residual contaminants, and site restoration with placement of 2-ft thick sediment cap and riprap as scour protection. Temporary facilities were removed following completion of construction including: water treatment system, stormwater diversion berms, and temporary fences. River access ramps were re-graded. Disturbed areas were re-vegetated using a native seed mix. The RCMs (patented permeable composite mats consisting of reactive materials encapsulated in a non-woven core matrix bound between two geotextiles) were placed to treat contaminants carried by advective or diffusive flow, which allowed for a thinner cap thickness (than traditional sand caps) with the added stability and physical isolation provided by the geotextiles materials.

Mechanical dredging and capping was selected for WBGCR Reaches 3 and 4-5 due to dry conditions majority of year. The criteria used to evaluate the remedial alternatives include:

- overall protectiveness increase with volume of sediment removed
- performance increase with volume of sediment removed
- long-term effectiveness increase with use of high-preference remediation technologies
- short-term risk management decrease with increased dredging
- feasibility
- consideration of public concerns addresses the volume of contamination.
- restoration time-frame
- probable cost

Final selected remedy: Alternative 5B - Removal of Sediments and Capping to Meet PRGs and to Reduce Ecological and Human Health Risks to Acceptable Levels in Reaches 1, 2, 3, 4, 5, and Roxana Marsh.

Multiple lines of evidence were used to evaluate sediment impacts, including bulk sediment, pore water and elutriate chemistry data, as well as biological community and habitat assessments. Pore-water samples from the WBGCR were shown to be severely toxic to fish. Benthic invertebrate communities were shown to be altered with a reduction in the abundance of preferred fish food organisms. Fish populations inhabiting the WBGCR were found to be severely reduced, most likely as a result of severe habitat degradation. Sediment contaminant concentrations frequently exceeded the levels that have been established to protect piscivorous wildlife species (such as herons, kingfishers, and mink). Therefore, it was concluded that contaminated sediments were adversely affecting fish and wildlife resources using habitats in the WBGCR.

Site characterization, remedial options plan, engineering design, and remedial construction for Reaches 3 and 4-5 completed in fall 2011; remedial construction for Reaches 1-2 planned for summer 2012; engineering design for Reaches 6-7 currently in progress; long-term monitoring plan for Reaches 3 and 4-5 in progress (planned completion fall 2011).

A.80.6 Monitoring

TBD / Long-term Monitoring Plan was scheduled for completion fall 2011.

Costs: The project was funded by 65% USEPA and 35% IDNR/IDEM cost-share agreement under Great Lakes Legacy Act. The project budget was $31.1M for WBGCR Reach 3. The project was also funded by U.S. Department of Interior Natural Resource Damage Assessment and Restoration Program settlement funds. Related upland restoration activities near the Grand Calumet River have been under way for many years, including protection and restoration of rare habitats such as dune and swale and native prairies, as part of a larger Chicago/Northwest Indiana Corridor where a regional restoration plan is in place. The WBGCR sediment remediation and shoreline restoration activities will complement the ongoing habitat restoration efforts in this area.

RAOs/project objectives achieved? The project is viewed as a success.

A.80.7 References

USEPA. Legacy Act Grand Calumet River Cleanup Gets Underway. 2009.http://epa.gov-/glnpo/sediment/legacy/grandcal/grdcalFactsht2.pdf.

http://scholarworks.umass.edu/cgi/viewcontent.cgi?article=1165&context=soilsproceedings&sei-redir-=1#searc-h=%22West%20Branch%20Grand%20Calumet%20River%20sediment%20remediation%20Tetra%20Tech.

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Development and Evaluation of Risk-Based Preliminary Remediation Goals for Selected Sediment-Associated Contaminants of Concern in the West Branch of the Grand Calumet River. http://www.in.gov/idem/files/grandcal_prg_report_nov05.pdf.

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A.81 White Lake (OCC), MI

A.81.1 Summary

Environment:	Freshwater
Scale:	Full
Contaminants of Concern:	1996 concentrations averages: Total Chromium: 2,108 mg/kg Organic Chromium: 161 mg/kg Arsenic: 36 mg/kg Mercury: 1.6 mg/kg Tannery waste
Final Remedy:	Hydraulic cutterhead dredge and Barge Mounted Excavator. Dewatered on sectional barges and in Geotubes. The material was treated prior to disposal at an off-site landfill. Some areas were backfilled after dredging.

A.81.2 Site Description

Year: 2003

Water Depth: 10–15 ft

Target Volume: 76,000 yd^3

Actual Volume Removed: 85,000 yd^3

A.81.3 Remedial Objectives

Chromium concentrations less than 1,000 ppm.

Arsenic concentrations less than 20 ppm.

Contaminated sediment area: 6.2 acres of Tannery Bay

A.81.4 Remedial Approach

Hydraulic cutter head dredge, barge mounted excavator

A.81.5 Monitoring

Resuspension: Silt curtains were installed to control suspension. Turbidity monitoring was done outside silt curtains to ensure contaminates were not dispersing.

Performance: Vast amounts of tannery waste removed from site. Most contaminants stemmed from the tannery waste.

Residuals: Postdredging concentration before capping:

Total Cr: 4463 mg/kg

As: 117 mg/kg

One year after dredging:

Total Cr: 2716 mg/kg

Organic Cr: 58 mg/kg

As: 30 mg/kg

Hg: 2.0 mg/kg

A.81.6 References

Major Contaminated Sediment Sites Database; Sept. 2004 as updated 2008. http://www.s-mwg.org/MCSS_Database/MCSS_Database_Docs.html.

Great Lakes Areas of Concern; as updated July 2012. http://www.epa.gov-/greatlakes/aoc/whitelake/index.html.

A.82 Wyckoff-Eagle Harbor, WA

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A.82.2 Summary

Environment:	Subtidal and intertidal areas
Scale:	Full
Contaminants of Concern:	Creosote, pentachlorophenol, various polycyclic aromatic hydrocarbons, and heavy metals
Final Remedy:	Capping, MNR, and institutional controls

A.82.3 Site Description

The Wyckoff-Eagle Harbor Superfund site is located off the east side of Bainbridge Island, Washington. Due to operation of the former Wyckoff wood-treating facility and a former shipyard, the area was added to the USEPA's Superfund National Priority List (NPL) in 1987.

A.82.4 Remedial Approach

Final selected remedy: Capping, MNR, and institutional controls

In 1993 and 1994, USEPA capped a 54-acre subtidal hotspot area as part of a non-time-critical removal action. In September 1994, USEPA issued a ROD which called for monitoring and maintaining the existing sediment cap, and capping remaining subtidal areas of concern, monitoring the success of natural recovery in intertidal areas, enhancing existing institutional controls to reduce public exposure to contaminated fish and shellfish, long-term monitoring of the sediment cap, and demolishing in-water structures. The additional capping involved 15 acres in a nearshore area and intertidal area and was conducted in 2000-2001. In 2002, 50,000 yd^3 of clean upland borrow material was placed in shallow subtidal and intertidal areas to create intertidal habitat and to form a continuous intertidal beach along the Eagle Harbor shoreline.

A.82.5 Monitoring

RAOs/project objectives achieved? Three five-year reviews of the site have been conducted with the most recent (USEPA 2014) concluding that the remedy continues to function as intended. The area of the subtidal cap within a ferry navigation lane and an area (grid J9) that may not have been capped initially show less than target cap thicknesses, but otherwise, the cap thickness is stable. Prior to remediation, 80% of harbor English sole exhibited toxicopathic liver lesions but sampling between 2000 and 2002 found a significant decreasing trend in biliary fluorescent compounds and significantly decreased lesions (Myers et al. 2008). Recent passive sampling efforts (Thomas, Lu, and Reible 2012) showed no evidence of contaminant migration through the cap except potentially in the area J9 that was identified in the third five year review as having a cap of less than target thickness and which may not have been capped during the remedy implementation.

The intertidal cap areas remain within target thickness, show effective contaminant isolation of underlying contaminated sediments, and provide habitat, although 2011 sampling indicated some potential PAH exposure near shore and beach areas where potentially mobile NAPL has been noted.

A.82.6 References

USEPA. Wyckoff Eagle Harbor Superfund Site, USEPA Region 10, last updated August 2014, http://y-osemite.epa.gov-/R10/CLEANUP.nsf/2ae189540953f4038825777b007b9e3a/62575003bd4e619088257a7e00802c50!Ope .

Eagle Harbor Wyckoff, State of Washington, Department of Ecology, https://-fortress.wa.gov/ecy/gsp/Sitepage.aspx?csid=2683.

A.83 Willamette River, Portland, OR

A.83.1 Contacts

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A.83.2 Summary

Environment:	River
Scale:	Full
Contaminants of Concern:	PCBs, metals, PAHs, TBT
Source Control Achieved Prior to Remedy Selection?	Source control, dredging, sand/rock cap, MNR
Final Remedy:	Shoreline removal, in-water capping

A.83.3 Site Description

The Zidell waterfront property consists of 32.17 acres in Section 10, Township 1 South, Range 1 East of the Willamette Meridian. The site is located at 3121 SW Moody Avenue in Portland, Multnomah County, Oregon. The property is bordered by SW Moody Avenue on the west, by property zoned for commercial use on the north (currently vacant property owned by the Oregon Health Sciences University [OHSU]), and by the former Pacific Metals facility on the south currently under redevelopment. The site is bordered to the east by the Willamette River between river miles 13 and 15. Zidell Marine Corporation and Zidell both operate on the site, which varies from 70 ft to 850 ft wide (east to west), and is 3,300 ft long (north to south).

Historically, the site was used for building, dismantling, converting, repairing, and salvaging ships and barges. It was also used for scrap metal operations, wire burning and aluminum smelting, and housing construction. The south part of the site is currently used for barge construction, and the north part is vacant or used to store salvage materials.

The primary source of contamination at the site is the long history of ship dismantling activities and barge construction.

CSM summary: The primary source of sediment contamination appears to be related to past ship dismantling activities and fires along the dock. Organotin contamination is most likely associated with paint chips produced by sand blasting. The source of metals is most likely sand-blasting grit, paint chips (chromium, copper, and lead), and other parts of the ships. PCBs may have been contained in cables, gaskets, paint, and elsewhere in older ships, as well as in transformers dismantled at the site. The PAHs and petroleum hydrocarbons may have been generated during ship and tank dismantling as well as during dock fires. The source of COIs may also be particulates suspended in stormwater discharged to the Willamette River through stormwater outfalls, surface soils eroded from the upland portion or bank of the site, historical groundwater discharges to the Willamette River, and suspended sediment transported from upriver sources. Many factors influence the transport, fate, and bioavailability of chemicals in sediments and their partitioning into pore water, including the type of chemical (nonpolar hydrophobic organic compounds and metals), the chemistry of the environment (oxic versus anoxic, marine versus freshwater), physical conditions (grain size, disturbance, and stability of the sediments), the amount and source of organic carbon in sediments (humic material, coal, soot, oil), the pH and concentration of ammonia in pore water, and the presence of metal sulfides in sediment.

A.83.4 Remedial Objectives

Site risks: Upland portions of the site pose an unacceptable risk to future residents and current and future excavation and construction workers. Existing sediment contamination within 200 ft of the shoreline poses an unacceptable risk to recreational anglers through the fish ingestion pathway.

Upland portions of the site pose an unacceptable risk to ecological receptors including terrestrial species, birds, plants and invertebrates. Existing sediment contamination within the Willamette River and along the shoreline of the site poses an unacceptable risk to sediment dwelling organisms and other ecological receptors (such as birds and mammals) through food web exposures.

RAO(s)/Project objectives:

Medium RAOs:

- Prevent future residents and worker exposure to soil containing constituents exceeding acceptable risk-based concentration (RBC) values.
- Prevent ecological receptors from exposure to soil containing CPECs exceeding DEQ SLVs.
- Prevent transport of COCs/CECs in soil to the Willamette River through stabilization of shoreline and stormwater runoff controls.
- Remediate soil hot spots to the extent feasible.
- Protect humans against exposure to site-related COCs above protective levels.
- Minimize transport of sediment containing COCs and CECs above cleanup levels to down-stream areas of the river.
- Ensure sediments contaminated with CECs above protective levels do not become accessible to benthic organisms, or aquatic and terrestrial organisms through food chain exposure.
- Remediate hot spots of contamination in sediment by reducing their concentration, volume, or mobility to the extent feasible and practical.
- Protect ecological habitat and beneficial uses of surface water adjacent to the facility.

A.83.5 Remedial Approach

Final selected remedy: Removal/dredging and capping, MNR

The selected remedial action for contaminated soil consists of the following elements:

- Interim source control measures to prevent releases of hazardous substances to the Willamette River from upland and bank soils through stormwater runoff.
- Excavation and off-site disposal of up to 8,000 yd^3 of contaminated soil exceeding hot spot concentrations, and asbestos containing material.

- On-site consolidation of soil exceeding cleanup levels from Greenway Area or future public right-of-ways to non-Greenway area of the site prior to capping.
- Re-grading the Greenway shoreline to facilitate placement of a soil cap above an elevation of 13 ft and upgrading existing armoring of the riverbank from 13 ft to the Willamette River sediment surface to minimize future releases of hazardous substances in soil to the Willamette River.
- Engineering controls involving placement of a cap over residual soil contamination exceeding risk-based concentrations.
- Institutional controls involving inspection and maintenance of the soil cap and protocols for future sub-surface maintenance activities.

The selected remedial action for contaminated sediments consists of the following elements:

- Engineering controls to include placement of a clean sand/rock cap over up to 17 acres of contaminated sediment along the Zidell shoreline.
- Institutional controls involving inspection and maintenance of the sediment cap.
- Periodic reviews by DEQ.
- Selective sediment dredging/capping of the barge launchway to facilitate continued site operations or possible future use of the area for public access for river-related activities.
- The sediment remedy also includes MNR for sediment outside the cap.

Why was the remedy selected? A total of seven alternatives were considered for soil and five alternatives were considered for sediment. Selected remedy was based on consideration of long and short-term effectiveness, feasibility, reliability, and cost.

A.83.6 Monitoring

Monitoring elements: Controls were placed in the river to reduce turbidity generated during capping. Capping methods were selected to limit disturbance of underlying sediment. Divers were used to collect samples from the cap after initial placement. Sampling after cap is placed will occur to document that contaminated material was not displaced during capping and to provide a baseline for MNR monitoring.

RAOs/project objectives achieved? Remedy implementation in progress.

A.83.7 Advantages and Limitations

Site Specific Challenges:

- Regulatory—Lengthy discussions and revised proposals due to cap placement permitting. Armoring material was ultimately covered with rock determined to be fish friendly.
- Technical—Coordination with bridge construction that overlapped with cap area was required.

A.83.8 References

Oregon Department of Environmental Quality - Zidell Waterfront Property. http://www.deq.state.or.us/lq/cu/nwr/zidell/index.htm.

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APPENDIX C. ACRONYMS

AC activated carbon
ACS American Chemical Society
ADCP acoustic Doppler current profile
ADV acoustic Doppler velocimeter
ADCP acoustic Doppler current profiler
AET apparent effects threshold
AOC area of concern
APG Aberdeen Proving Ground
ARAR all relevant and appropriate regulations
ASTSWMO Association Of State And Territorial Solid Waste Management Officials
AVS/SEM acid volatile sulfide/simultaneously extracted metals
AWQC ambient water quality criteria
BAF bioaccumulation factor
BAZ biologically active zone
BCF bioconcentration factor
BES U.S. Department of Energy, Office of Basic Energy Sciences
BMP best management practices
BNC Bremerton Proving Ground
BNL Brookhaven National Laboratory
BOD biological oxygen demand
BSAF biota-sediment accumulation factor
BTEX benzene, toluene, ethylbenzene, and xylene
CA corrective action
CAD contained aquatic disposal
CAIT Center for Advanced Infrastructure and Transportation
CAMU Corrective Action Management Unit
CDF confined disposal facility
CEC cation exchange capacity
CERCLA Comprehensive Environmental Response, Compensation, and Liability Act
C_{Free} carbon free
CMS corrective measures study
COC contaminant of concern
COPC contaminant of potential concern
CRA comparative risk analysis
CSM conceptual site model
CSO combined sewer outfall
CUAA ceded and usual and accustomed areas
CWA Clean Water Act
DDD dichlorodiphenyldichloroethane
DDE dichlorodiphenyltrichloroethylene
DDT dichlorodiphenyltrichloroethane
DDX dimethyl dioxane
DNAPL dense nonaqueous phase liquid
DOC dissolved organic carbon
DOE U.S. Department of Energy
DOT Department of Transportation
DQO date quality objective
DRET dredge residual elutriate test
EDA emergency declaration area
EDLE East Doane Lake Remediation
EE environmental evaluation
EM environmental management
EMNR enhanced monitored natural recovery

ESA	Endangered Species Act
ESD	explanation of significant difference
FDA	U.S. Food and Drug Administration
FS	feasibility study
GAC	granular activated carbon
GCL	geosynthetic clay liner
GE	General Electric
GHG	greenhouse gas
GLLA	Great Lakes Legacy Act
GLNPO	Great Lakes National Program Office
GPS	geographic positioning system
GSR	green and sustainable remediation
GIS	geographic information system
GWTS	groundwater treatment and collection system
HDPE	high density polyethylene
IDEM	Indiana Department of Environmental Management
ITRC	Interstate Technology and Regulatory Council
ISS	in situ stabilization
IST	in situ treatment
LCARA	Love Canal Area Revitalization Area
LOAEL	lowest observed adverse effect level
LTMP	long term management plan
MCDA	multi-criteria decision analysis
MEC	munitions and explosives of concern
MGP	manufactured gas plant
MLLW	mean low level water
MNR	monitored natural recovery
MRSOU	Milltown Reserve Sediment Operable Unit
NAPL	nonaqueous phase liquid
NFA	no further action
NJDOT	New Jersey Department of Transportation
NOAA	National Oceanic and Atmospheric Administration
NOAEL	no observed adverse effect level
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
NSB	Naval Station Bremerton
OC	organic carbon
OCC	Occidental Chemical Corp.
OCF	on-site contaminated facility
ORP	oxidation reduction potential
OU	operable unit
PAH	petroleum halogenated hydrocarbon
PARCC	precision, accuracy, representativeness, comparability, completeness, and sensitivity
PCB	polychlorinated biphenyl
PDM	processed dredged material
PEC	probable effects concentration
PC-ADP	pulse coherent acoustic Doppler profiler
PCDD	polychlorinated dibenzo-dioxins
PCDF	polychlorinated dibenzo-furans
PEC	probable effect concentration
POC	particulate organic carbon
POTW	publicly owned treatment works
PRGs	preliminary remedial goals
PRP	potentially responsible party

PSF	pounds per square foot
QA/QC	quality assurance/quality control
RAO	remedial action objective
RCM	Reactive Core Mat
R&D	research and development
RCRA	Resource Conservation and Recovery Act
RfD	reference dose
RG	remediation goal
RI	remedial investigation
RI/FS	remedial investigation/feasibility study
ROD	Record of Decision
RR&R	release, resuspension and residuals
SARA	Superfund Amendments and Reauthorization Act
SAV	submerged aquatic vegetation
SDWA	Safe Drinking Water Act
SE	standard error
SED	survey of earned doctorates
SEDA	sediment erosion and deposition assessment
SMART	specific, measurable, attainable, relevant, and time-bound
SPI	sediment profiling imaging
SRB	sulfate-reducing bacteria
SSCC	site specific cleanup criteria
STE	sediment transport evaluation
SVOC	semivolatile organic compound
SWAC	surface weighted actions concentrations
TBT	tributyltin
TCE	trichloroethene
TOC	total organic carbon
TPH	total petroleum hydrocarbon
TSCA	Toxic Substances Control Act
TSD	treatment, storage and disposal facility
TMDL	total maximum daily load
UCL	upper confidence limit or upper control limit
USACE	U.S. Army Corp of Engineers
UXO	unexploded ordnance
VOC	volatile organic compound
w/w	wet weight
ZVI	zero-valent iron

APPENDIX D. GLOSSARY

A

abatement
The act or process of lessening, reducing, or removing material or contaminants.

abiotic degradation
Process in which a substance is converted to simpler products by physical or chemical mechanisms; examples include hydrolysis and photolysis.

absorption
Absorption is the assimilation or incorporation of a gas, liquid, or dissolved substance into another substance.

adsorption
Adsorption is the adhesion of molecules of gas, liquid, or dissolved solids to a surface. The term also refers to a method of treating wastes in which activated carbon is used to remove organic compounds from wastewater. Additionally, Adsorption is defined as the process by which nutrients such as inorganic phosphorous adhere to particles via a loose chemical bond with the surface of clay particles.

advection
Bulk transport of the mass of discrete chemical or biological constituents by fluid flow within a receiving water. Advection describes the mass transport due to the velocity, or flow, of the water body. It is also defined as: The process of transfer of fluids (vapors or liquid) through a geologic formation in response to a pressure gradient that may be caused by changes in barometric pressure, water table levels, wind fluctuations, or infiltration.

advective groundwater flux
The rate or movement of chemical or biological materials within a groundwater system per unit time in response to a concentration gradient or some advective force.

anthropogenic activity
Activity resulting from human activities.

apatite
Name given to a group of phosphate minerals, usually referring to hydroxylapatite distributed widely in igneous, metamorphic, and sedimentary rocks, often in the form of cryptocrystalline fragments. Hydroxylapatite is used in chromatographic techniques to purify proteins and other chemicals.

B

background (reference conditions)
When used in sediment characterization studies, refers to both the concentrations of COPC that are not a result of the activities at the site undergoing assessment and the locations of the background areas (MacDonald and Ingersoll 2002). Therefore, there are two types of background recognized by USEPA and many states: naturally occurring background and anthropogenic background. Users should verify whether their state and/or USEPA region has different definitions and requirements for assessing background conditions as part of environmental site assessments.

bathymetry
The measurement of or the information from water depth at various places in a body of water.

benthic habitat
The benthic habitat is the ecological region at the lowest level of a body of water such as an ocean or a lake, including the sediment surface and some subsurface layers.

bentomats
A reinforced geosynthetic clay liner (GCL) using sodium bentonite integrated into a geotextile matrix used in landfills, surface water impoundments and for secondary containment.

bioaccessible
Describes the fraction of a chemical that desorbs from its matrix (such as soil, dust, or wood) in the gastrointestinal tract and is available for absorption. The bioaccessible fraction is not necessarily equal to the relative bioavailability but depends on the relation between results from a particular in vitro test system and an appropriate in vivo model.

bioaccumulation
The accumulation of substances, such as pesticides, or other organic chemicals in an organism. Bioaccumulation occurs when an organism absorbs a toxic substance at a rate greater than that at which the substance is lost. Thus, the longer the biological half-life of the substance the greater the risk of chronic poisoning, even if environmental levels of the toxin are not very high.

bioaccumulation factor (BAF)
The ratio of COPC in tissue to the COPC concentration in an external environmental phase (water, sediment, or food) (Spacie, Mccarty, and Rand 1995). The BAF is typically assumed to be measured or expressed on a steady-state basis. For applications to the water phase, the BAF is best determined from field data where sampled organisms are exposed to chemical measured in the water and their diet. For applications in reference to the

sediment and food phases, the BAF is expressed using concentrations in the tissue and environmental phase on a wet weight basis or dry weight basis, for example, (µg/g of w/w tissue)/(µg/g of w/w food), (µg/g of d/w tissue)/(µg/g of d/w food), and (µg/g of d/w tissue)/(µg/g of d/w sediment). This definition of BAF is used for metals, organometallic compounds, and organic compounds. For clarity, the BAF is expressed with the units in subscripts. For the concentration in the tissue phase, the numerator (N subscript) is the basis of the tissue phase (L for lipid-normalized, WW for wet weight, and DW for dry weight bases). For the environmental phase, the denominator (D subscript) is the basis for the water (FD for freely dissolved, T for total, and D for dissolved/filtered water), food (WW for wet weight and DW for dry weight), or sediment (WW for wet weight, and DW for dry weight) phases. Some commonly used BAF expressions are as follows: • BAFL/FD = where concentrations in tissue and water are on a lipid and freely dissolved basis, respectively • BAFWW/T = where concentrations in tissue and water are on a wet weight and total basis, respectively • BAFDW/DW = where concentrations in tissue and sediment are both on a dry weight basis

bioaugmentation

Use of (microbes) to clean up oil spills or remove other pollutants from soil, water, or wastewater.

bioavailability

The relationship between external (or applied) dose and internal (or resulting) dose of the chemical(s) being considered for an effect (NRC 2003).

bioavailability processes

Individual physical, chemical, and biological interactions that determine the exposure of plants and animals to chemicals associated with soils and sediments (NRC 2003).

biochars

Biomass that has been carbonized under thermal conditions less intense than those that are used to form activated carbon.

bioconcentration factor

The ratio of the steady-state COPC concentration in an aquatic organism (CB) and the COPC concentration in water (CW) determined in a controlled laboratory experiment where the test organisms are exposed to chemical in the water (but not the diet). In the subscript, the numerator (N) is the basis of the tissue phase (L for lipid-normalized, WW for wet weight, and DW for dry weight bases) and denominator (D) is the basis for the water phase (FD for freely dissolved, T for total, and D for dissolved/filtered water). Commonly used BCF expressions are as follows: • BCFL/FD = where concentrations in tissue and water are on a lipid and freely dissolved basis, respectively • BCFWW/T = where concentrations in tissue and water are on a wet weight and total basis, respectively •

BCFDW/T = where concentrations in tissue and water are on a dry weight and total basis, respectively

biomagnification factor (field based)
The ratio of the chemical concentrations in an aquatic or terrestrial organism (CB) and in the diet of the organism (CD) determined from field-collected animals that are exposed to chemical in air, water and diet. The numerator (N) is the basis of the tissue phase (L for lipid-normalized, WW for wet weight, and DW for dry weight bases) and denominator (D) is the basis for the diet (L for lipid-normalized, WW for wet weight, and DW for dry weight bases). Two commonly used BMF expressions are as follows: • BMFL/L = where concentrations in tissue and diet are on a lipid basis • BMFVWW/WW = where concentrations in tissue and diet are on a wet weight basis

biomagnification factor (laboratory based)
The ratio of the steady-state chemical concentrations in an aquatic or terrestrial organism (CB) and in the diet of the organism (CD) determined in a controlled laboratory experiment, where the test organisms are exposed to chemical in the diet (but not water or air). In the subscript, the numerator (N) is the basis of the tissue phase (L for lipid-normalized, WW for wet weight, and DW for dry weight bases) and denominator (D) is the basis for the diet (L for lipid, WW for wet weight, and DW for dry weight bases). Commonly used BMF expressions are as follows: • BMFL/L = where concentrations in tissue and diet are on lipid basis • BMFWW/WW = where concentrations in tissue and diet are on wet weight basis • BMFDW/DW = where concentrations in tissue and diet are on dry weight basis

biomimetic device
A diffusion-based sampler that is designed to "mimic" an aquatic organism (for example, a semi-permeable-membrane device is dialysis tubing filled with a purified fish oil like triolein).

biostimulation
Modification of the environment to stimulate existing bacteria capable of bioremediation.

biota sediment accumulation factor (BSAF
Ratio of the chemical concentration in an aquatic organism (CB, in g chemical/kg lipid) and in the sediment from the site where the organism was collected (CS, in g chemical/kg organic carbon) determined from field or laboratory data: BSAF = CB/CS.

bioturbation.
The displacement and mixing of sediment particles and solutes by fauna (animals) or flora (plants).

bulk concentration
In water, the total COPC concentration in a bulk (unfiltered) sample of water (kg of COPC/L of water). In sediment, the total COPC concentration in a bulk sediment sample

(kg COPC/kg dry sediment).

C

cap

A covering over material (contaminated sediment) used to isolate the contaminants from the surrounding environment.

capping

Technology which covers contaminated sediment with material to isolate the contaminants from the surrounding environment.

carbon normalization

For sediment, dividing a bulk organic COPC concentration (for example, mg/kg fluoranthene) by the fraction of TOC measured in the same sample (such as 0.02 g carbon/g sediment, or 2% TOC).

chemical transformation

abiotic or biotic chemical process (such as photolysis, hydrolysis, oxidation/reduction, radioactive decay) that transform an element (Cr(VI) - Cr III) or compound (phenol – CO_2+ H_2O) to a different element or chemical compound.

chemical warfare material (CWM)

Chemical materials used in warfare, such as explosives, toxic gases, defoliants, for the ultimate purpose of defeating the enemy.

Clean Air Act (CAA)

Rule passed in 1970 that sets nationwide ambient air quality standards for conventional air pollutants. CAA sets standards for emissions from both stationary and mobile sources (for example, motor vehicles).

Clean Water Act (CWA)

Rule passed in 1972 that mandates "fishable/swimmable" waters wherever attainable. Provides for (1) a construction grants program for publicly owned water treatment plants and requires plants to achieve the equivalent of secondary treatment; (2) a permit system to regulate point sources of pollution; (3) area wide water quality.

Compensation and Liability Act (CERCLA).

Passed in 1980, commonly known as Superfund, this act covers the cleanup of hazardous substance spills, from vessels, active, or inactive facilities. Establishes a Hazardous Substances Response Trust Fund, financed by a tax on the sale of hazardous chemicals, to be used for removal and cleanup of hazardous waste releases. Cleanup costs must be shared by the affected state. Within certain limits and subject to a few defenses, anyone associated with the release is strictly liable to reimburse the fund for cleanup costs, including damage to natural resources.

Comprehensive Environmental Response
Passed in 1980, commonly known as Superfund, this act covers the cleanup of hazardous substance spills, from vessels, active, or inactive facilities. Establishes a Hazardous Substances Response Trust Fund, financed by a tax on the sale of hazardous chemicals, to be used for removal and cleanup of hazardous waste releases. Cleanup costs must be shared by the affected state. Within certain limits and subject to a few defenses, anyone associated with the release is strictly liable to reimburse the fund for cleanup costs, including damage to natural resources.

conceptual site model (CSM)
A representation of an environmental system and the biological, physical and chemical processes that determine the transport and fate of contaminants through environmental media to environmental receptors and their most likely exposure modes.

constituents of concern (COCs)
Materials or structures in an ecosystem that may have an effect on that or other environments. These may consist of chemicals, biota, natural features or any other thing that could affect the area of concern.

contaminant flux
The ebb and flow of contaminants from and through an ecosystem.

contaminant(s) of potential concern (COPC)
In a risk assessment, a substance detected at a hazardous waste site that has the potential to affect receptors adversely due to its concentration, distribution, and mode of toxicity (USEPA 1997b). COPCs are generally categorized operationally, based on how they are measured in the analytical laboratory. "Inorganic" COPCs generally address metals, elements, and unique inorganic compounds such as perchlorate. "Organic" COPCs include VOCs (such as acetone, benzene, and trichloroethylene), SVOCs (such as chlorophenols, chlorobenzenes, and phthalate esters), pesticides (such as atrazine, DDT, toxaphene), PCBs, and polychlorinated dibenzodioxin and dibenzofurans.

contaminants of concern (COCs)
Contaminants in an ecosystem that may have an effect on that or other environments. These may consist of chemicals, biota, natural features or any other thing that could affect the area of concern.

contaminated sediment remedial alternatives
Combinations of technologies used in sequence or in parallel to remediate a contaminated site.

critical shear stress
The shear stress at which a small but measurable rate of erosion occurs (related to strength of the sediment).

cut face diffusion
Diffusion from the sloughing of the sidewalls and headwall of the dredge cut face back on to previously dredged areas.

D

degradation (chemical)
1) Changes brought about to an environment, ecosystem or physical structure due to interaction with a chemical or chemicals; 2) change of the composition and structure of a chemical due to influences from its environment.

deposition rate
The amount of material deposited per unit time or volume flow.

diffusion sampler
A semi-permeable membrane or dialysis tube filled with distilled water or gel, which relies on solute gradient to establish equilibrium between pore water and the sampler.

diffusive flux
A law describing the diffusion that occurs when solutions of different concentrations come into contact with molecules moving from regions of higher concentration to regions of lower concentration. Fick's law states that the rate of diffusion dn/dt, called the "diffusive flux" and denoted J, across an area A is given by $dn/dt = J = -DA\partial c/\partial x$, where D is a constant called the "diffusion constant," $\partial c/\partial x$ is the concentration gradient of the solute, and dn/dt is the amount of solute crossing the area A per unit time. D is constant for a specific solute and solvent at a specific temperature. Fick's law was formulated by the German physiologist Adolf Eugen Fick (1829–1901) in 1855.

diffusive gradient in thin films (DGT)
A sampler that is typically filled with a gel that is designed to target a specific compound (for example, binding of metals).

direct sources
Direct sources include effluent outfalls from factories, refineries, waste treatment plants, and similar facilities that emit fluids of varying quality directly into urban water supplies.

discarded military munitions (DMM)
Munitions used by the military in war time or piece that are no further value to them. These are commonly, explosives and explosive devices, small and large arm ammunition, chemical warfare compounds, and byproducts of military activities.

dispersion

1) Pollutant or concentration mixing due to turbulent physical processes; 2) A distribution of finely divided particles in a medium.

dissolved concentration

In water, the concentration of COPC in filtered water, traditionally defined as water that will pass through a 0.45 µm filter.

E

ebullition

The act, process, or state of bubbling up usually in a violent or sudden display.

endocrine disruptors

Endocrine disruptors are chemicals that may interfere with the body's endocrine system and produce adverse developmental, reproductive, neurological, and immune effects in both humans and wildlife. A wide range of substances, both natural and artificial, are thought to cause endocrine disruption, including pharmaceuticals, dioxin and dioxin-like compounds, polychlorinated biphenyls, DDT and other pesticides, and plasticizers such as bisphenol A. Endocrine disruptors may be found in many everyday products– including plastic bottles, metal food cans, detergents, flame retardants, food, toys, cosmetics, and pesticides. The NIEHS supports studies to determine whether exposure to endocrine disruptors may result in human health effects including lowered fertility and an increased incidence of endometriosis and some cancers. Research shows that endocrine disruptors may pose the greatest risk during prenatal and early postnatal development when organ and neural systems are forming. http://www.niehs.nih.gov/health/topics/agents/endocrine/

enhanced monitored natural recovery (EMNR)

Used to reduce the concentration of chemicals in the biologically active zone of sediment in a manner that would enhance the potential for ecologically balanced recolonization, while not causing widespread disturbance to the existing habitat. EMNR technology relies on a combination of enhanced natural recovery via placing a thin (6-12 in or 15-30 cm) layer of clean sediment over contaminated sediment and an effective characterization and monitoring program to project and verify recovery.

epibenthic

On or above the sediment/water interface.

epifauna

Benthic invertebrates that live almost exclusively on or upon the benthic substrate. The substrate can range from soft silt or clay in a lentic environment to sand, gravel, pebbles, cobble, and boulders in a lotic environment.

equilibrium partitioning theory
A theory developed in the late 1980s as a means of predicting toxicity of PAHs to sediment-dwelling organisms. It posits that the toxicity to sediment organisms is directly proportional to the amount of unbound PAH dissolved in sediment pore water.

exposure pathway
The channel or path followed by pollutants from their source, via air, soil, water, and food to humans, animals, and the environment.

F

food-web magnification factor
See trophic magnification factor.

freely dissolved
The concentration of the chemical that is freely dissolved in water, excluding the portion sorbed onto particulate and dissolved organic carbon (kg of chemical/L of water). Freely dissolved concentrations can be estimated with an empirical equation with knowledge of the Kpoc and Kdoc and can be measured with passive samplers, such as POM, SPMD, SPME, and PE.

fugacity
A measure of a chemical potential in the form of "adjusted pressure." It reflects the tendency of a substance to prefer one phase (liquid, solid, or gas) over another and can be literally defined as "the tendency to flee or escape."

fugacity samplers
Polymeric materials inserted into sediment that accumulate hydrophobic organic compounds in proportion to their surface area.

G

gavage
Introduction of nutritive material into the stomach by means of a tube.

geochemistry
1) Science that deals with the chemical composition of and chemical changes in the solid matter of the earth or a celestial body (as the moon); 2) The related chemical and geological properties of a substance.

geomembrane
A kind of geosynthetic material made up of an impermeable membranes. Their uses include solid waste containment (such as landfill liners), mining, and water containment applications.

geomorphology
Study of the evolution and configuration of landforms.

H

high density polyethylene (HDPE)
A high density linear polyethylene made from petroleum, often used as a liner for waste disposal interments.

hydraulic dredging
Dredging by use of a large suction pipe mounted on a hull and supported and moved about by a boom, a mechanical agitator, or cutter head which churns up earth in front of the pipe, and centrifugal pumps mounted on a dredge which suck up water and loose solids.

hydrodynamics
The branch of science that deals with the dynamics of fluids, especially that are incompressible, in motion.

hydrodynamics data
Information on the on the flow rates and volumes of a system, including other data pertinent to the hydraulic function of a waterway.

hypolentic
Transition zone between groundwater and surface water beneath lakes and wetlands (USEPA 2010).

hyporheic zone
The hyporheic zone is an active ecotone between the surface stream and groundwater. Exchanges of water, nutrients, and organic matter occur in response to variations in discharge and bed topography and porosity. Upwelling subsurface water supplies stream organisms with nutrients while downwelling stream water provides dissolved oxygen and organic matter to microbes and invertebrates in the hyporheic zone. Dynamic gradients exist at all scales and vary temporally. At the microscale, gradients in redox potential control chemical and microbially mediated nutrient transformations occurring on particle surfaces.

I

in situ treatment (IST)
Treatment conducted while the subject or material is in its natural environment.

indirect sources
Like a source except the object to which it is attached knows very little about it, and requires another object to provide the pertinent information.

infauna
Benthic invertebrates that live almost exclusively in or below the sediment/water interface. These are generally tube- or burrow-dwelling organisms that feed at either the sediment/water interface or burrow and ingest sediments and/or sediment-dwelling organisms.

institutional controls
Non-engineered instruments, such as administrative and legal controls, that help minimize the potential for human exposure to contamination and/or protect the integrity of the remedy.

K

kg of organic carbon/kg of lipid).
Ratio of the chemical concentration in an aquatic organism (CB, in g chemical/kg lipid) and in the sediment from the site where the organism was collected (CS, in g chemical/kg organic carbon) determined from field or laboratory data: BSAF = CB/CS.

L

labile
Easily altered.

leaching
Leaching is the extraction of certain materials from a carrier into a liquid; usually, but not always, a solvent.

ligand
Complexing chemical (ion, molecule, or molecular group) that interacts with a metal to form a larger complex (USEPA 2003a).

lines of evidence
Pieces of evidence are organized to show relationships among multiple hypotheses or complex interactions among agent, events, or processes. A weight of evidence approach includes the assignment of a numeric weight to each line of evidence.

lipid-normalization
The COPC concentration in tissue (kg of chemical/kg of wet tissue) divided by the concentration of lipid in that tissue (kg of lipid/kg of wet tissue) or the COPC concentration in tissue (kg of chemical/kg of dry tissue) divided by the concentration of lipid in that tissue (kg of lipid/kg of dry tissue).

M

macroinvertebrate
Any organism that will, after sieving out surface water and fine suspended matter, be retained on a 0.5 mm mesh (No. 35 Standard Sieve) screen.

megasite
A large area, usually 5 – 500 km^2, with multiple contaminant sources.

monitored natural recovery (MNR)
A remedy for contaminated sediment that typically uses ongoing, naturally occurring processes to contain, destroy, or reduce the bioavailability or toxicity of contaminants in sediments. These processes may include physical, biological, and chemical mechanisms that act together to reduce the risk posed by the contaminants.

munitions and explosives of concern (MEC)
This term distinguishes specific categories of military munitions that may pose unique explosives safety risks means: Unexploded ordnance (UXO), discarded military munitions (DMM), and munitions constituents (such as TNT or RDX) present in high enough concentrations to pose an explosive hazard.

munitions constituents (MC)
Any materials originating from unexploded ordnance (UXO), discarded military munitions (DMM), or other military munitions, including explosive and non-explosive materials, and emission, degradation, or breakdown elements of such ordnance or munitions.

N

National Contingency Plan (NCP)
Passed in 1988, this five-step process is used to evaluate contaminated sites and suggest the best plan for remediation.

National Marine Sanctuaries Act (NMSA)
The National Marine Sanctuaries Act mandates that parties who destroy, cause the loss of, or injure sanctuary resources are responsible for their restoration.

nepheloid layer
A layer of water, above the bed or floor, that contains significant amounts of suspended sediments.

nonaqueous phase liquid (NAPL)
A liquid solution that does not mix easily with water. Many common groundwater contaminants, including chlorinated solvents and many petroleum products, enter the subsurface in nonaqueous-phase solutions.

O

octanol-water partition coefficient (Kow)
The ratio of a chemical concentration in 1-octanol (Co) and water (Cw) in an octanol-water system that has reached a chemical equilibrium: Kow = Co/Cw. Unitless.

Oil Pollution Act of 1990 (OPA)
OPA, along with the CWA and CERCLA, mandates that parties that release hazardous materials and oil into the environment are responsible not only for the cost of cleaning up the release, but also for restoring any injury to natural resources that results.

organophilic clay
Clay minerals whose surfaces have been ion exchanged with a chemical to make them oil-sorbent. Bentonite and hectorite (plate-like clays) and attapulgite and sepiolite (rod-shaped clays) are treated with oil-wetting agents during manufacturing. Quaternary fatty-acid amine is applied to the clay. Amine may be applied to dry clay during grinding or it can be applied to clay dispersed in water.

P

permeability
1) Characteristic of a material or membrane that allows liquids or gases to pass through it; 2) The rate of flow of a liquid or gas through a porous material.

pH
A measure of the acidity or alkalinity of a solution, numerically equal to 7 for neutral solutions, increasing with increasing alkalinity and decreasing with increasing acidity. The pH scale commonly in use ranges from 0 to 14.

phytoremediation
A bioremediation process that uses various types of plants to remove, transfer, stabilize, and/or destroy contaminants in the soil and groundwater. There are several different types of phytoremediation mechanisms.

pore water
Water located in the interstitial compartment (between solid-phase particles) of bulk sediment.

pore water expression
A technique used to serve to determine pore water ionic content.

precipitation
1) The formation of a solid in a solution or inside another solid during a chemical reaction or by diffusion in a solid; or 2) rain, sleet, hail, snow and other forms of water falling from

the sky.

R

radioactive decay
The process by which an atomic nucleus of an unstable atom loses energy by emitting ionizing particles (ionizing radiation). There are many different types of radioactive decay.

receptor
A plant, animal, or human that is typically the focus of a risk assessment following the direct or indirect exposure to a potentially toxic substance.

reference location (control)
An aquatic sediment system unaffected by COPCs which can be used in a baseline comparison of like parameters in a similar contaminated system. See entry for background.

remedial action objective (RAO)
Specific goals for protecting human health and the environment. RAOs are developed by evaluating Applicable or relevant and Appropriate Requirements (ARARs) that are protective of human health and the environment and the results of the remedial investigations, including the human and ecological risk assessments.

remediation
The act or process of abating, cleaning up, containing, or removing a substance (usually hazardous or infectious) from an environment.

remotely operated vehicle (ROV)
A vehicle that can be operated without a driver in the vehicle. These are often used for site investigations in areas where there are toxic or oxygen deficient atmospheres.

reproductive habitat
An environment where reproduction can occur, usually expressed as species specific.

Resource Conservation and Recovery Act (RCRA)
Enacted in 1976, this provides a comprehensive management scheme for hazardous waste disposal. This includes a system to track the transportation of wastes and federal performance standards for hazardous waste treatment, storage, and disposal facilities. Open dumps are prohibited.

resuspension
A renewed suspension of insoluble particles after they have been precipitated.

resuspension flux
The movement of a contaminant through a liquid (or gaseous media) upon resuspension of contaminated sediments.

S

screening

The comparison (by ratio, usually the environmental medium concentration divided by a benchmark, standard, criterion, or similar value) of site conditions to a screening value. Often this is synonymous with "compare to a list that is readily available."

sediment erosion and deposition assessment (SEDA)

A formal process that: 1) Identifies processes/mechanisms that might result in erosion and deposition; 2) Determines the most appropriate methods to assess erosion and deposition; and 3) Quantifies erosion and deposition under varying flow conditions.

sediment quality guideline (SQG)

Same as SQV except a guideline is typically issued by a regulatory agency or, in rare cases, promulgated via a state law.

sediment quality objective (SQO)

Same as SQV and SQG in some state-specific standards and rules.

sediment quality value (SQV)

A numerical (bulk concentration) benchmark below which a lesser adverse effect (or no adverse effect) is anticipated and above which a greater adverse effect is anticipated sequestration. The act of segregation. In environmental terms this usually refers to separation of materials by use of various technologies. Carbon sequestration refers to the capture and removal of of CO_2 from the atmosphere through biological or physical processes.

seiche

When wind drives water to one side of a water body thus increasing water levels and causing the potential for flooding. This effect can be significant in large lakes such as the Great Lakes.

sequestration

The act of segregation. In environmental terms this usually refers to separation of materials by use of various technologies. Carbon sequestration refers to the capture and removal of of CO2 from the atmosphere through biological or physical processes.

soil screening level

See "Regional Screening Table" at www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm.

solidification

To make solid, compact, or hard, to make strong or united, or to become solid or united.

sorption
The process in which one substance takes up or holds another; adsorption or absorption.

source control
Those efforts that are taken to eliminate or reduce, to the extent practicable, the release of COCs from direct and indirect ongoing sources to the aquatic system being evaluated.

spatial component
That part of a description that defines an object's position or location.

stakeholder
Affected tribes, community members, members of environmental and community advocacy groups, and local governments.

sulfhydryl
Thiol is a compound that contains the functional group composed of a sulfur atom and a hydrogen atom (-SH). Being the sulfur analogue of an alcohol group (-OH), this functional group is referred to either as a "thiol group" or a "sulfhydryl group."

Superfund Amendments and Reauthorization Act (SARA)
Passed in 1986, SARA provides cleanup standards and stipulates rules through the National Contingency Plan for the selection and review of remedial actions. It strongly recommends that remedial actions use on-site treatments that "permanently and significantly reduce the volume, toxicity, or mobility of hazardous substances" and requires remedial action that is "protective of human health and the environment, that is cost-effective, and that utilizes permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable."

Surface Mining Control and Reclamation Act (SMCRA)
Passed in 1977, it regulates coal surface mining on private lands and strip mining on public lands. Prohibits surface mining in environmentally sensitive areas.

T

temporal component
That part of a description that defines an object or activity in regard to time.

total maximum daily load (TMDL)
A maximum amount of pollutant(s) that can be present in a body of water without exceeding regulatory limits.

Toxic Substances Control Act (TSCA)
Enacted in 1976 this act requires premarket notification of EPA by the manufacturer of a new chemical. Based on testing information submitted by the manufacturer or premarket test ordered by EPA (including biodegradability and toxicity), a court injunction can be

obtained barring the chemical from distribution or sale. EPA can also seek a recall of chemicals already on the market. This act prohibits all but closed-circuit uses of PCBs.

toxicity unit
A unit formerly synonymous with "minimum lethal dose" but which, because of the instability of toxins, is now measured in terms of the quantity of standard antitoxin with which a toxin combines. See www.biology-online.org/dictionary/Toxic_unit.

trophic interactions
The interactions among producers and organisms that consume and decompose them.

trophic magnification factor or food-web magnification factor (TMF or FWMF)
The average factor by which the normalized chemical concentration in biota of a food web increases with each increase in trophic level. The TMF is determined from the slope (m) derived by plotting the logarithmically transformed (base 10) lipid-normalized chemical concentration in biota vs. the trophic position of the sampled biota (as TMF = 10m). Unitless.

U

unexploded ordnance (UXO)
Explosive weapons (such as bombs, bullets, shells, grenades, land mines, naval mines) that did not explode when they were used and still pose a detonation risk, potentially many decades after they were used or discarded.

W

water column
1) The basic habitat and the medium through which all other fish habitats are connected; 2) a conceptual column of water from surface to bottom sediments. This concept is used chiefly for environmental studies evaluating the stratification or mixing (such as by wind induced currents) of the thermal or chemically stratified layers in a lake, stream or ocean. Some of the common parameters analyzed in the water column are: pH, turbidity, temperature, salinity, total dissolved solids, various pesticides, pathogens and a wide variety of chemicals and biota. Understanding water columns is important, because many aquatic phenomena are explained by the incomplete vertical mixing of chemical, physical or biological parameters. For example, when studying the metabolism of benthic organisms, it is the specific bottom layer concentration of available chemicals in the water column that is meaningful, rather than the average value of those chemicals throughout the water column.

water column transport
Movement within a water column due to changes in certain parameters (see water column).

Z

zeolites

Microporous, aluminosilicate minerals commonly used as commercial adsorbents.